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AT
TENNESSEE STATE UNIVERSITY

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This Fourth annual Report provides an overview of the research activities in the Center for Neural Engineering (CNE) comprising consortium partners: Tennessee State University (TSU), Caltech, Meharry Medical College (MMC), North East Ohio Universities College of Medicine (NEOUCOM), Oak Ridge National Laboratior (ORNL), and the University of Southwest Louisiana (USL). MMC and NEOUCOM provided the experimental data. A team of eight (8) researchers along with (5) undergraduate students and twelve (12) graduate students conducted research at the Center. The CNE also supported a Ph.D student at NEOUCOM. CNE conducted research in various aspects of neural computation and applied these techniques to dynamic control aircraft, (helicopter), signal classification (image processing), spatial navigation (mobile robot) medical diagnosis and oscillatory hippocampal network (spatial information processing). The research led to the completion of three Masters Theses and three senior projects; one book chapter, four referenced papters, six non-referenced conference papers and three new grants in the areas of communication, condition based maintenance, and data acquisition system for medical diagnosis.

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MESSAGE FROM THE DEAN

The Center for Neural Engineering was established in the College of Engineering and Technology in May, 1992, with a grant in excess of $1.3 million from the Office of Naval Research to conduct research in neural networks.

During the past four years, the Center has witnessed the growth of partnerships with other industries (small and large) and universities (HBCU/MI and others).

As a spinoff, the Center has successfully competed for additional research projects from NASA (especially STTR) DOE, National Security Agency, NSF, Ventrans Administration, McDonnell Douglas and Lockheed Martin (ONRL Manufacturing Center).

The College of Engineering and Technology wishes to express its pride in the achievement of Center researchers, and the quality of their research, as evidenced by the increase in the number of publications and presentations at the regional, national, and international conferences. We are also proud of the caliber of our students, both undergraduate and graduate, involved in this exciting critical technology of biologically inspired neural networks.

Decatur B. Rogers, P.E., Ph.D.
Dean, College of Engineering and Technology

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Summary

This Fourth Annual Report provides an overview of the research activities in the Center for Neural Engineering (CNE) comprising consortium partners: Tennessee State University (TSU), Caltech, Meharry Medical College (MMC), North East Ohio Universities College of Medicine (NEOUCOM), Oak Ridge National Laboratory (ORNL), and the University of Southwest Louisiana (USL). NEOUCOM is providing an experimental data under a subcontract from the CNE.

The format of this report is provided by the Sponsor, Office of the Naval Research (ONR) for Historically Black Colleges and Universities (HBCU) Science and Engineering Education Programs. A team of eight (8) researchers along with five (5) undergraduate students and twelve (12) graduate students conducted research at the Center. The CNE also supported a Ph.D student at NEOUCOM.

The Center wishes to thank the Board of Directors; Dr. Bill Appleton, Mr. Donald Campbell, Dr. Joel Davis, Dr. Harold Szu and Dr. James Townsel for their guidance and valuable suggestions for the growth of the Center. The Center used the ONR grant as leverage to attract an additional three grants from NASA, NSF and VA Hospital to apply neural network technologies to their problems.

The home page for the World Wide Web (WWW) site for the CNE at TSU is located at `http://acad.tnstate.edu/~eecneweb/indexcne.htm`. It can also be reached through the WWW site for TSU, the home page of which is located at `http://acad.tnstate.edu`. First, go to the home page of the TSU web site. Next, click on the button marked "Other Web Sites". Finally, click the button marked "CNE" under the heading "TSU Other Servers/Home Pages". The CNE web site contains a diverse and growing set of information about the CNE at TSU, including a mission statement, research areas, staff, facilities, consortia partners, and contact information.

This report summarizes the faculty activities, curriculum changes/enhancement, student activities and facilities supported by this grant. The program objectives for the next year and the interaction among consortium partners are also mentioned.

1 Overview of Scientific Progress

The Center for Neural Engineering (CNE) conducted research in various aspects of neural computation and applied these techniques to dynamic control (helicopter), signal classification (image processing), spatial navigation (mobile robot) and oscillatory hippocampal network (spatial information processing). The research led to the completion of three Masters Theses and three senior projects; one book chapter, four referenced papers, six non-referenced conference papers and three new grants in the areas of communication, condition based maintenance, and data acquisition system for medical diagnosis. The grants are funded by NASA, NSF, and the VA Hospital, respectively.

2 Goals and Objectives

The main objectives of the Center are:

1. To advance the understanding of biologically motivated neural network systems through inter-disciplinary basic research.

2. To develop the highest quality undergraduate and graduate curricula in neural computing and engineering that will serve as a role model for other institutions.

3. To provide pre-graduate and post-graduate training for students in a nationally and internationally recognized basic and applied research and development environment focusing on critical present and future technologies.

4. To broaden educational and career development opportunities for minorities and for women.

The Center addressed the above objectives through the following specific tasks:

1. Develop an intelligent aircraft control system testbed for real-time hardware/software miniature helicopter control. The testbed is created for center researchers to test advanced control algorithms (possibly neural network based), and for student senior projects, Masters Theses, and research projects. In addition, expertise gained in the development process will be applied to other ongoing and proposed Center testbeds.

2. Apply fuzzy neural networks to the design of a compact, real-time representation of aerodynamic data that is capable of executing on an on-board aircraft flight computer. Specifically, the neural network is to represent stability and control derivative terms that are used by the flight control algorithms.

3. Contribute to the development of an acoustic/structural control strategy for application to launch vehicles. Specifically, acoustic excitation to a payload contained inside a rocket payload fairing is to be reduced during rocket lift-off and ascent.

4. Apply various neural network architectures and algorithms in the areas of auditory response, speech coding, neuromuscular signal decomposition and prosthesis control and sensory motor control systems.

5. Develop a neural network-based system which will mimic the auditory response from a rat's auditory cortex exited by successive pure tones. The data is provided by Meharry Medical College.

6. Develop biologically-inspired neural network architecture for mobile robot control and implementation.

7. Conduct research through experiments in the Meharry Medical College to:

   - Develop experiment to record action potentials from the cardiac epicardial tissue from anesthesized dogs stimulated externally under normal tyrode solution and with drug clofillium using varying stimulus frequencies.
   - Develop chaos analysis tools to determine whether biphasic restitution of action potential duration in ventricular muscle permits the development of complex dynamic behavior.
   - Develop artificial neural network-based control system to control the drug induced abnormal responses of the tissue to its normal behavior by injecting controlled current.

8. Provide research experience for undergraduate and graduate students in the area of biological auditory and sensory motor system, neural networks and chaos and help undergraduate students complete their senior projects.

9. Provide professional development activities for research faculty through attendance at national meetings, short courses and seminars.

10. Present papers at regional, national, and international conferences.

11. Publish papers in conference proceedings and scientific journals.

3 Faculty Mentoring Activities

Dr. Mohammed Bodruzzaman (elect. eng.), Dr. Mohit Bhatacharyyia (MMC), Dr. John Kuschewski (CNE), Dr. Amir Shirkhodaie (mech. engr.), Dr. Tim Teyler (NEOUCOM), Dr. Geoffrey Yuen (CNE), and Dr. Saleh Zein-Sabatto (elect. engr.) guided five (5) undergraduate student (elect. eng.), eleven (11) graduate students (elect. engr.), and one (1) Ph.D. student (physiology) on various projects as discussed below.

Dr. Bodruzzaman supervised five graduate and two undergraduate students. They are Carolyn Keaton, Srinivasa Ramamurthy, Anuradha Gulamudi, Jesse Boyce, Shaik Faheem, Kevin McFerren and Christopher Mosby. Srinivasa Ramamurthy completed his Masters

Thesis on "Neural Network-Based Target (Image) Recognition and Classification" and graduated in May 1996. Kevin McFerren and Christopher Mosby started their senior project in spring 1996 and left for summer jobs in ORNL. They will use their experimental data, collected in ORNL, and continue working on their senior project in fall 1996.

The laboratories of Dr. Bhattacharyyia and Dr. Sanika Chirwa were selected as consortium (subcontractor) laboratories. These laboratories have ongoing research programs in which biological data was collected with potential utility in the development of new neural networks.

Dr. Kuschewski co-advised (with Dr. Zein-Sabatto) three graduate students: Othman Al-Smadi, Vivian Dorsey, and Terriance Moody. Vivian Dorsey is currently working on "Design of Artificial Limb Using Spherical Joints". Terriance Moody is currently working on "Design of a Distal Teacher Recursive Estimator for an Airplane Flight Controller".

Dr. Yuen supervised or co-advised four graduate students: Jarvis Spruill, Srinivasa Ramamurthy, Carolyn Keaton and Anuradha Gulamudi. Jarvis Spruill completed his Masters Thesis on "Hippocampal Navigation Neural Networks" and graduated in January 1996. Srinivasa Ramamurthy completed his Masters Thesis on "Neural Network-Based Target (Image) Recognition and Classification" and graduated in May 1996. Carolyn Keaton will complete her Masters Thesis on "Oscillatory Neural Networks for Spatial Information Processing" and graduate in August 1996. Anuradha Gulamudi is currently working on "Pulse-coded Neural Network-Based Image Recognition and Classification".

Dr. Zein-Sabatto conducted mentoring activities through regular research meetings and appointments. All students made research presentations and they were provided with constructive criticism at the time. During the Fall of '95 and Spring of '96 semesters three undergraduates and five graduate students were supervised by Dr. Zein-Sabatto under research supported by CNE/ONR. They are: Lisa Elkridge, Erika Hopkins, and Larry Word (undergraduate students) and Vivian Dorsey, Rajeev Gupta, Terriance Moody, Jarvis Spruill, and Yixiong Zheng (graduate students).

Other mentoring activities include monthly written progress reports and semester progress reports from each student.

Of the eighteen students, thirteen are U.S. citizens and eleven (5 females and 6 males) are U.S. born African-Americans. Table 1 presents the academic and research information for these students.

Table 1: Student academic and research information.

Name	Major	Class	Research Project Title	Advisor(s)
Jesse Boyce	EE	Graduate	Neuro-fuzzy system-based predictive maintenance	Dr. Bodruzzaman
Vivian Dorsey	EE	Graduate	Design of artificial limb using spherical joints	Dr. Zein-Sabatto Dr. Kuschewski
Steven Drews	EE	Graduate	Intelligent controller for mobile robot	Dr. Zein-Sabatto
Lisa Elkridge	EE	Junior	Design of artificial limb using spherical joints	Dr. Zein-Sabatto
Shaik Faheem	EE	Graduate	Chaos analysis and control of cardiac system	Dr. Bodruzzaman Dr. Bhattacharyyia
Anuradha Gulamudi	EE	Graduate	Oscillatory neural network for invariant target recognition	Dr. Bodruzzaman Dr. Yuen
Rajeev Gupta	EE	Graduate	Intelligent helicopter yaw control	Dr. Zein-Sabatto
Erika Hopkins	EE	Junior	Mobile robot for path navigation	Dr. Zein-Sabatto
Carolyn Keaton	EE	Graduate	Oscillatory neural networks for spatial information processing	Dr. Bodruzzaman Dr. Yuen, Dr. Teyler
Kevin McFerren	EE	Junior	Predictive maintenance fuzzy logic system	Dr. Bodruzzaman Dr. Carter
Terriance Moody	EE	Graduate	Design of a distal teacher recursive estimator for an airplane flight controller	Dr. Zein-Sabatto
Deimetra Moore	EE	Graduate	Design of an intelligent flight control system for helicopter roll-axis control	Dr. Zein-Sabatto
Steve Morgan	Physiology NEOUCOM	Ph.D.	Neural models of hippo-campal synaptic plasticity for spatial navigation	Dr. Teyler Dr. Yuen
Christopher Mosby	EE	Junior	Predictive maintenance using neural network	Dr. Bodruzzaman Dr. Carter
Srinivasa Ramamurthy	EE	Graduate	Neural network based target recognition and classification	Dr. Bodruzzaman Dr. Yuen
Jarvis Spruill	EE	Graduate	Hippocampal navigation neural networks	Dr. Yuen Dr. Zein-Sabatto
Larry Word	EE	Senior	Design of neurocontroller for inverted pendulum	Dr. Zein-Sabatto
Yixiong Zheng	EE	Graduate	Intelligent helicopter altitude control	Dr. Zein-Sabatto

4 Student Projects

1. **Neuro-Fuzzy System-Based Predictive Maintenance** (Jesse Boyce, graduate student, Graduation Date: December 1996, Advisor(s): Dr. Bodruzzaman).

   Vibrational analysis of damaged machinery is one approach for detecting faults which occur in rotating machinery. In the area of Preventive Maintenance, vibrational analysis has proven to be a nondestructive and cost effective technique for predicting the machine fault before it occurs. The dynamic behavior of rotating machinery has been studied in many papers. In this project, we will add a Neuro-Fuzzy classification system that will be able to classify a particular fault into its proper class in an Off-line Data Acquisition System. The data used to train the classification system was obtained by extracting the time history fault features of a particular fault using modern signal processing techniques. The neuro-classification system is composed of an Artificial Neural Network (ANN). The fuzzy classification system is composed of a Fuzzy Logic classifier. These two systems used together are able to classify real vibration data into their proper class to allow the end user to determine what type of maintainence action should be taken for a particular machine.

2. **Design of Artificial Limb Using Spherical Joints** (Vivian Dorsey, graduate student, Graduation Date: December 1996, Advisor(s): Dr. Zein-Sabatto and Dr. Kuschewski).

   This project involves the design of a 4-DOF robot arm similar to a human arm. A neural network based controller will be designed and trained to control the arm. The trained neurocontroller generates the proper control signal for the spherical joints in order to produce a motion similar to a human movement. This project simulates how a biological system produces motion such as a biological shoulder or arm.

3. **Intelligent Controller for Mobile Robot** (Steven Drews, graduate student, Graduation Date: December 1997, Advisor(s): Dr. Zein-Sabatto).

4. **Design of Artificial Limb using Spherical Joints** (Lisa Elkridge, undergraduate student, Graduation Date: August 1997, Advisor(s): Dr. Zein-Sabatto).

5. **Chaos Analysis and Control of Cardiac System** (Shaik Faheem, graduate student, Graduation Date: May 1997, Advisor(s): Dr. Bodruzzaman and Dr. Bhattacharyyia (MMC)).

6. **Oscillatory Neural Network for Invariant Target Recognition** (Anuradha Gulamudi, graduate student, Graduation Date: December 1996, Advisor(s): Dr. Bodruzzaman and Dr. Yuen).

   The first stage in an image-understanding system is the preprocessing stage, which deals with early vision processing. In an image understanding system, the pre-processing stage performs functions such as gray scale manipulation, edge detection, developing descriptions of objects or shapes in the image, image restoration and geometric correction. There are a number of image processing operations that can be performed with

virtually no knowledge about the contents of the image. Image enhancement techniques deal with improving the image quality. Restoration techniques basically deal with inversion of the degrading process. Conventional techniques, as well as artificial neural network models, used in preprocessing are discussed.

7. **Intelligent Helicopter Yaw Control** (Rajeev Gupta, graduate student, Graduation Date: May 1997, Advisor(s): Dr. Zein-Sabatto).

   The complex behavior of helicopters has brought research attention to the area of control systems. One step towards such control is the intelligent control system. The goal of this project is to develop an intelligent control system that will make the control of helicopters easier and will be be able to automatically identify and accommodate mechanical failures in order to prevent accidents. Helicopters have six degrees of freedom (axes): x, y, z, roll, pitch, and yaw. The purpose of this research is to develop a model for proper measurement and control of the yaw axis of the helicopter. By yaw axis, we mean the clockwise or counter-clockwise rotation of the helicopter with respect to the x axis and referenced to an initial point. We used a gyroscope (gyro) to measure the yaw angle. The gyro receives input signals from a microprocessor and sends its output signals to a servo motor that controls the tail rotor angle. Whenever there is an angular motion in the helicopter, there is a difference in the gyro's input and output signals. This difference is used to measure the yaw angle of the helicopter.

   In order to do this, we have developed an experiment to study the gyro's behavior. The gyro is placed on a turntable whose angular speed is controlled by a dc motor. The input signal is given by a microprocessor (Basic Stamp) and the difference in the input and output pulses is measured by another microprocessor (Basic Stamp II). This difference, the input and output signals, and the angular velocity of the turntable is sent from the Basic Stamp II to the computer via RS-232C and stored in a file. The collected data is used to find the relationship between the difference of the gyro input and output pulses and the gyro's angular velocity. This relationship will be used to model the behavior of the yaw axis with respect to other parameters of the helicopter. The next step is to develop a neuro model which will be used to develop an intelligent controller for the yaw axis of the helicopter.

8. **Mobile Robot for Path Navigation** (Erika Hopkins, undergraduate student, Graduation Date: August 1997, Advisor(s): Dr. Zein-Sabatto).

9. **Oscillatory Neural Networks for Spatial Information Processing** (Carolyn Keaton, graduate student, Graduation Date: August 1996, Advisor(s): Dr. Bodruzzaman, Dr. Yuen and Dr. Teyler (NEOUCOM)).

   Visual perception of an object requires identification and integration of its attributes. Individual attributes are represented by distinct neuronal groups which are spatially distributed throughout regions of the brain. Perception is twofold: activation of the neuronal group which represents the attribute and binding these groups to identify the object. It is suggested that binding of neurons representing different attributes of an object is achieved by selective synchronization of temporally structured responses of the neurons activated by these attributes. The neuronal groups oscillate in response

to different attributes. The phase of oscillations link groups to represent a particular object. Thus, coding of objects in the brain is spatial-temporal, involving both the space and time domain. Experimental evidence in the visual cortex of animals support this hypothesis. Most conventional neural network algorithms use only the spatial domain to represent information. Since the brain performs recognition and perception task faster and more efficiently than any computer, incorporating brain network architecture can help develop artificial neural networks with fast and efficient recognition and retrieval properties. The goal of this research is then to develop an artificial neural network which incorporates the oscillatory behavior of the brain to recognize two-dimensional patterns. The three main objectives of this research are to: implement an oscillatory neural network in Neuron; introduce frequency-dependent learning and hippocampus-based network architecture into the network; and then test the network as a content-addressable memory trained to recognize two-dimensional patterns.

10. **Predictive Maintenance Fuzzy Logic System** (Kevin McFerren, undergraduate student, Graduation Date: May 1997, Advisor(s): Dr. Bodruzzaman and Dr. Carter (ORNL)).

11. **Design of a Distal Teacher Recursive Estimator for an Airplane Flight Controller** (Terriance Moody, graduate student, Graduation Date: August 1997, Advisor(s): Dr. Zein-Sabatto).

    This research concentrates on the design of an estimation system with sensory information provided by a dynamic system. It should also estimate any changes or variations in the parameters of that dynamic system model. the technique used in this research is based on the prediction provided by two neural networks. The first neural network, the Baseline Neural Network, predicts the nominal values of the system parameters. The second network will predict any variation or change in the system parameters. This network is called the Distal Teacher Network and is implemented on-line. This procedure of system parameter estimation will be tested on a model for advanced jet aircraft and will be used to provide the necessary information for operating an intelligent controller for the airplane.

12. **Design of an Intelligent Flight Control System for Helicopter Roll-axis Control** (Deimetra Moore, graduate student, Graduation Date: August 1997, Advisor(s): Dr. Zein-Sabatto).

    This research deals with the design of an intelligent flight control system that will be able to control the roll and pitch position of a helicopter. Since the helicopter is an unstable system, the controller will make the helicopter stabilize about the appropriate axis. The design will be a combination of hardware and software. The hardware will consist of two sensors, one for roll and one for pitch. The controller will consist of a combination of microprocessors and artificial neural networks (ANNs). There will be a combined software program development for the microprocessors and for the neurocontroller.

13. **Predictive Maintenance Using Neural Network** (Christopher Mosby, undergraduate student, Graduation Date: May 1997, Advisor(s): Dr. Bodruzzaman and Dr.

Carter (ORNL)).

14. **Neural Network-Based Target (Image) Recognition and Classification** (Srinivasa Ramamurthy, graduate student, Graduation Date: May 1996, Advisor(s): Dr. Bodruzzaman and Dr. Yuen).

    The aim of this project was to develop a new approach for effective recognition and classification of targets irrespective of their position, orientation and scale. Invariances can be easily incorporated into its structure. A method for reduction of the feature set is discussed and complete systems of moment invariants under translational, different scaling are derived. Classification is achieved using a neural network algorithm that is more effective than the traditional methods. It is shown that the recognition of targets independent of size and orientation can be accomplished and to support this many experimental results are described. The proposed approach has shown to be very effective giving high accuracy (100% for 5 objects).

15. **Hippocampal Navigation Neural Networks** (Jarvis Spruill, graduate student, Graduation Date: January 1996, Advisor(s): Dr. Yuen and Dr. Zein-Sabatto).

    The aim of this project was to implement and test a navigation neural network architecture originally constructed by Burgess et al 1994. We developed various analysis tools to show cases when the network is unreliable and propose modifications which can improve performance and robustness (i.e. frequency-dependent learning).

16. **Design of Neurocontroller for Inverted Pendulum** (Larry Word, undergraduate student, Graduation Date: May 1996, Advisor(s): Dr. Zein-Sabatto).

    This project involves the design and implementation of a neural network controller to control the inverted pendulum available at the Department of Electrical and Computer Engineering's Control Lab.

17. **Intelligent Helicopter Altitude Control** (Yixiong Zheng, graduate student, Graduation Date: December 1996, Advisor(s): Dr. Zein-Sabatto).

    Helicopters are inherently complex and nonlinear in nature due to coupled rotor-body interaction, so helicopter behavior of is difficult to model by conventional methods. Without a proper model, design of a proper controller is impossible. With the development of artificial neural network (ANN) technology, there emerges a new approach to model and control a complex system like a helicopter. This approach uses an ANN to model this nonlinear an complex mechanical system and to train a specially structured ANN to control the system. The objective of this research is directed toward finding a way to use an ANN to model and control helicopter altitude. We use a computer based helicopter testing system, which includes a small size computer controlled helicopter and sampling system, to obtain helicopter altitude and control signal information. We then find a properly structured ANN and train it to model the behavior of the helicopter. Using the ANN model, we can train an ANN controller to automatically control the helicopter to a certain altitude set by the pilot.

5 Student Presentations

The following students made presentations at the 18th Annual University-Wide Research Day, TSU, March 25-26, 1996:

1. Jesse Boyce presented "Pump motor vibration analysis and fault detection using neuro-fuzzy classification system".
2. Anuradha Gulamudi presented "Image enhancement and restoration".
3. Carolyn Keaton presented "Oscillatory neural network using frequency dependent learning".
4. Jame Osa presented "Neural network control of chaotic system".
5. Srinivasa Ramamurthy presented "Wavelet and oscillatory neural network-based object recognition and classification".
6. Other research students making presentations included Vivian Dorsey, Rajeev Gupta, Deimetra Moore, Larry Word, and Yixiong Zheng.

We are pleased to announce that the following students won awards. For her presentation, Carolyn Keaton won the research presentation award. Larry Word and Vivian Dorsey won the second place award in the undergraduate and graduate student presentation categories, respectively, for their presentations.

6 Faculty Research Highlights

6.1 Research Activities of Dr. Mohammad Bodruzzaman

Dr. Bodruzzaman conducted research in following areas:

6.1.1 Chaos Analysis and Control of Epicardial Tissue

This research activity is conducted in collaboration with Dr. Mohit Bhattacharyyia of MMC and the experiments are conducted in his laboratory. In the first phase of this project we are developing algorithms and codes for analyzing the responses from epicardial tissue (in-vitro). The purpose of this study is to determine whether biphasic restitution of action potential duration (APD) in ventricular muscle permits the development of complex dynamic behavior. Such behavior is expected because of the steep ascending slope of restitution and the presence of a maximum. Action potentials recorded from strips of epicardial muscle in which biphasic APD restitution occurred demonstrated a characteristic pattern of phase locking during progressive shortening of the pacing cycle length. 1:1 locking was replaced by irregular dynamics, which in turn was replaced by higher order periodic (e.g., 8:8 locking), then finally by 2:2 locking. Similar patterns of dynamic behavior were produced in a computer model

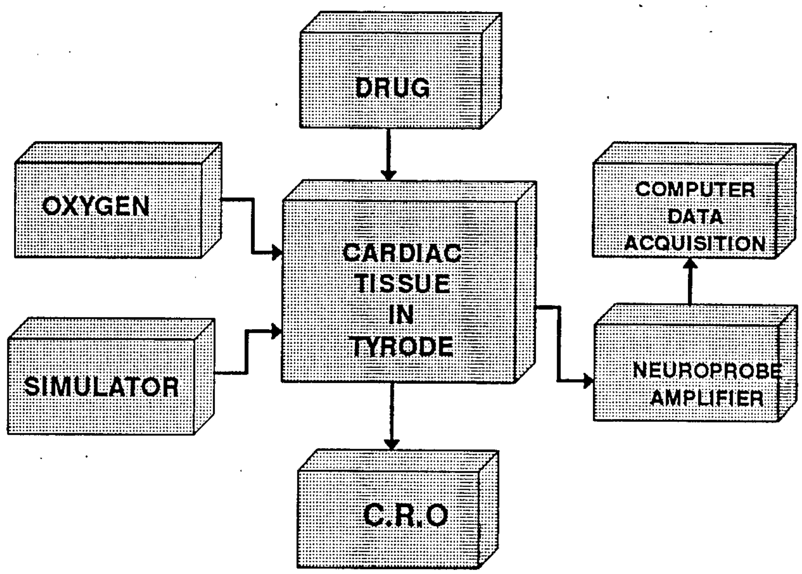

Figure 1: Experimental setup for data acquisition.

by using a piecewise linear approximation of biphasic APD restitution. Features of APD restitution that were critical determinants of irregular dynamics included the slopes of the ascending and the nonmonotonic regions. These results suggest that rate-related alterations of APD and refractoriness may be affected significantly by small nonmonotonicities in APD restitution.

The cardiac epicardial tissue taken from anesthetized dogs is simulated externally and the effect of simulation is studied. See Figure 1 for the experimental setup for data acquisition. The effect of different drugs on the tissue's action-potential is recorded. The abnormal condition of the tissue due to the drug inducement changes the action potential across the cell membrane. This phenomena helps us in understanding and analyzing the varying action potentials for increasing frequency of simulation. This is a situation where the tissue is forced to oscillate at frequency which is different from its natural rhythm. We have recorded action potentials in normal tyrode solution and with the drug clofillium. A typical normal response and drug affected response are shown in Figures 2 and 3 respectively. The chaos analysis tools have been developed to observe the chaotic behavior of these data by plotting the return maps, phase-plane plots, and Lyapunov exponents. Figures 4 and 5 show the results of typical return map and Lyapunov exponent plots. Next phase is to model these data using a suitable neural network and develop neural network-based control system to control the behavior of drug-induced cardiac tissue by injecting proper ammount of current. The overall project goals are shown in Figure 6.

Bibliography

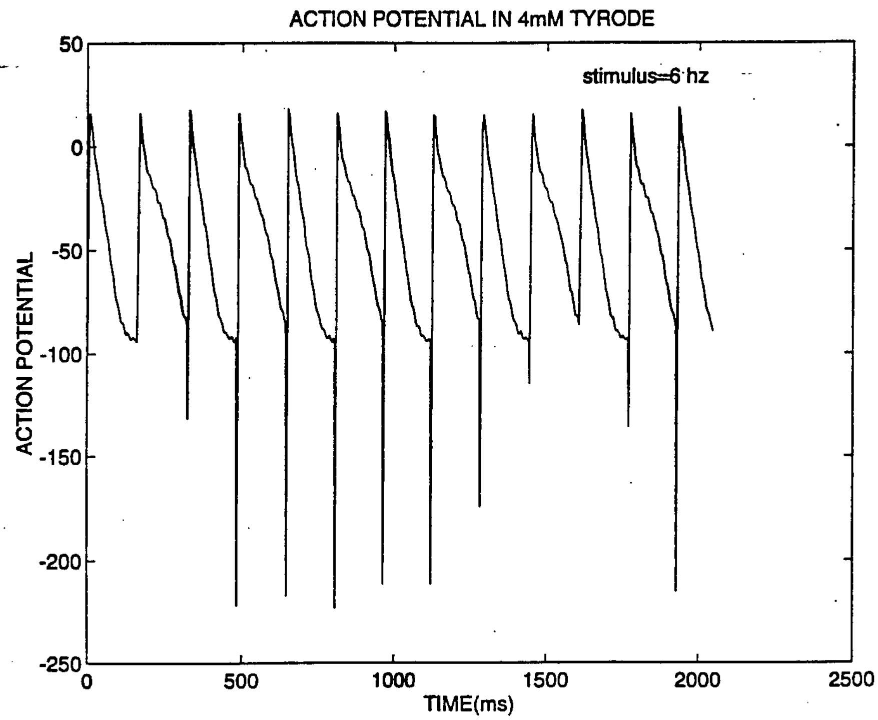

Figure 2: Normal response.

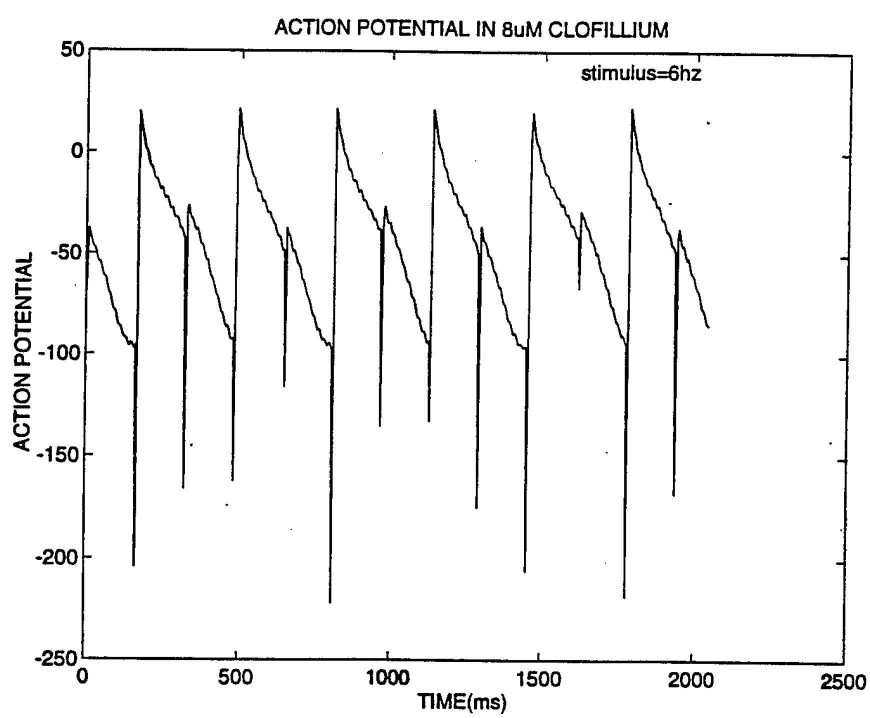

Figure 3: Drug affected response.

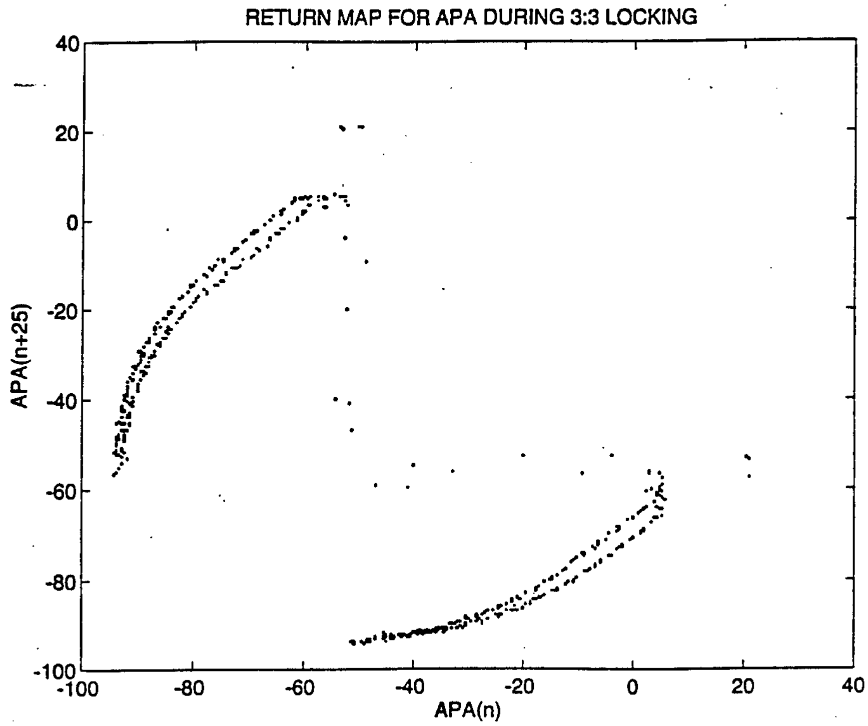

Figure 4: Return map plot of normal response.

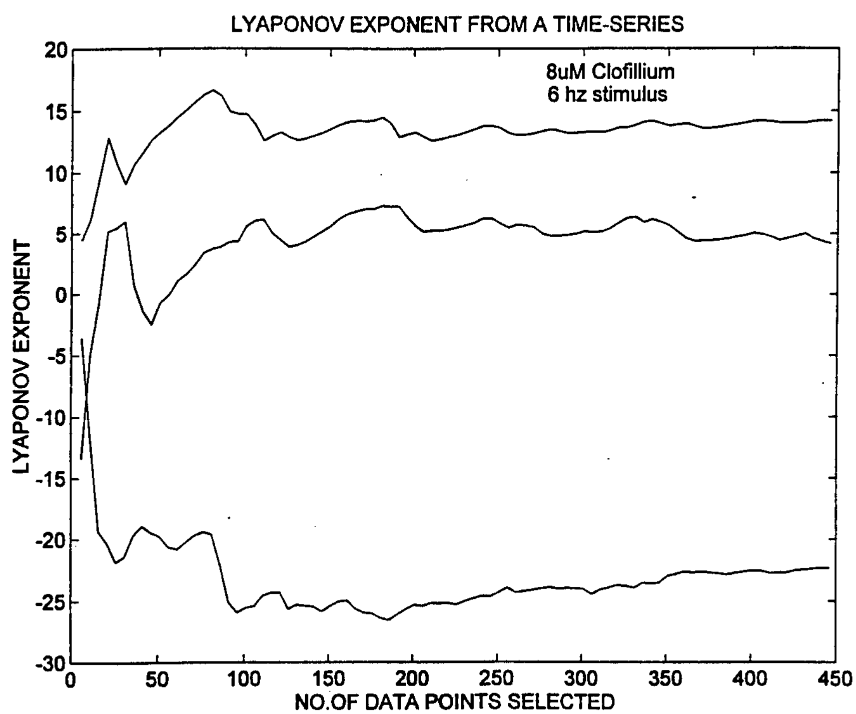

Figure 5: Lyapunov exponent plot of drug affected response.

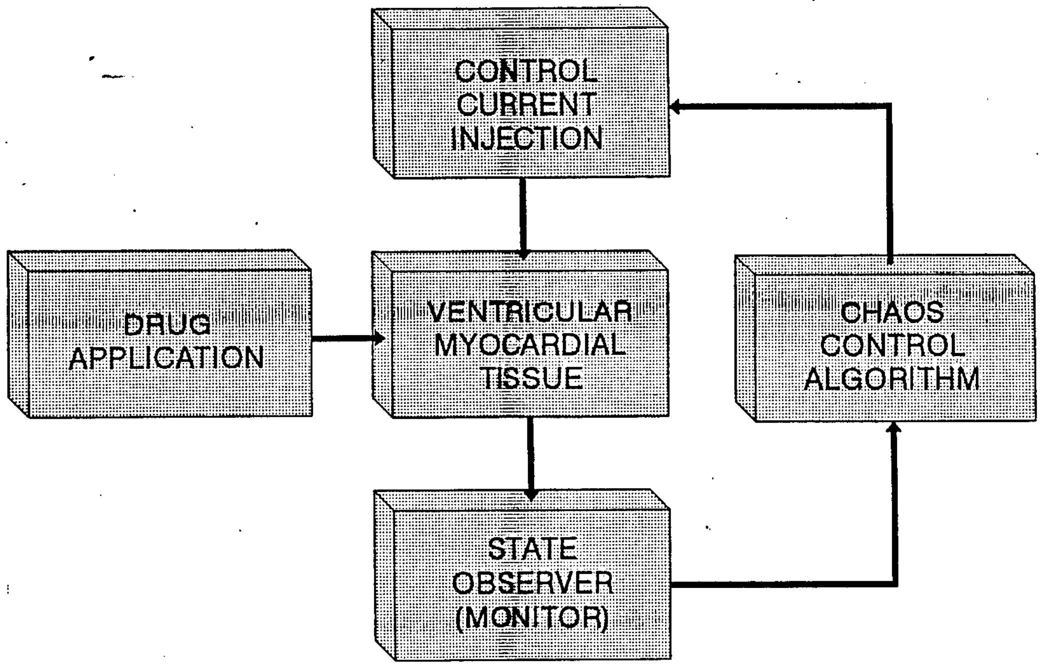

Figure 6: Overall project goals.

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6.1.2 Localization of Ventricular Arrhythmogenic Foci

The objective of this project is to improve "pace mapping", a technique that is used to locate the abnormal circuit of focus in the ventricle that gives rise to potentially lethal cardiac arrhythmias. Accurate localization of the site within the heart that is responsible for the arrhythmia will increase the success of treatment by radiofrequency ablation, a technique that modifies the electrical properties of the focus with high frequency electrical current. Currently we are investigating the possible use of the neural network technique of pattern matching to solve this problem. We started this project on June 1, 1996 in collaboration with Heart Station, Veteran Administration Hospital, Nashville. We developed A/D conversion

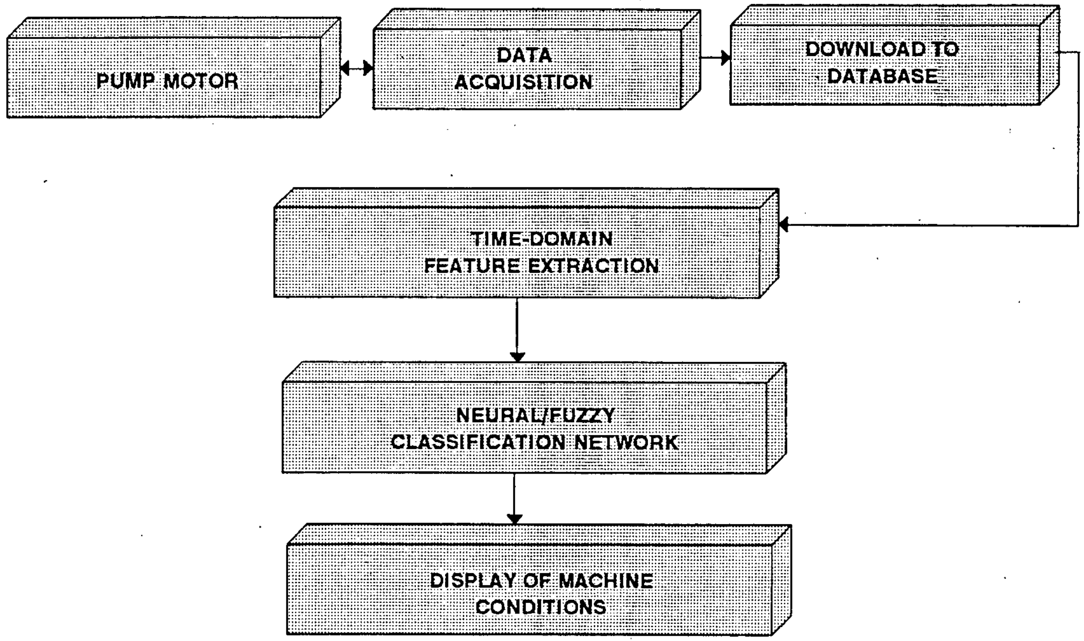

Figure 7: Pump motor diagnostic system.

programs using a laptop PC, National Equipment Data Acquisition system and visual C++ for real time-time display of the pace mapping signals.

6.1.3 Neuro-Fuzzy System for Predictive Maintenance

This research focuses on developing Neuro-Fuzzy system for predictive maintenance of a pump motor machinery system (Figure 7). A database was created using six pump towers. Each tower contains at least three pumps which were used to generate the vibration data. The data was collected at the Y-12 plant at ORNL under normal and several fault conditions such as bearing, cavitation, misalignment, and unbalanced faults. Effective feature sets were obtained from each data using parametric signal modeling and frequency domain analysis. These features were then used to train and test a feedforward network for classification of various faults. Currently a fuzzy logic system is also under development for comparison with the classification results obtained by neural network.

6.1.4 Chaos Analysis and Control of Fluid Bed Combustion System

The objective of this project is to develop a neuro-control technique to control the chaotic behavior in a Fluid Bed Combustion System (FBC). We have completed the neural network-based chaos control system and tested it on a variety of simulated chaotic systems. The results are very promising and it is possible to implement it on a real FBC plant to control the air flow valve by observing the chaotic pressure drop data.

6.1.5 Neural Network Modeling and Prediction of Ionogram Data

Long range HF radio communication is used for tactical and strategic military purposes, and for international broadcasting which depends on the ability of the ionosphere to return the radio signal incident on it back to earth. By far the most important layer from the radio viewpoint is the F2 layer due to its height and dominant electron density. From the point of view of radio communication, the most important parameter of an ionospheric layer is its critical frequency or parameter frequency. The seasonal variations of foE (critical frequency of E-layer) and foF1 (critical frequency of F1 layer) are in phase with the solar zenith angle whereas foF2 (ordinary ray critical frequency) tends to be in antiphase. The diurnal and seasonal variations of foF2 are very complicated and do not follow any simple dependence on X (zenith angle). Since our interest lies only in the F2 layer, only the foF2 parameter values are collected for a certain time period. This foF2 time series data are be modeled using various types of neural network architectures and tested for their prediction capability.

6.1.6 Neural Network Based Target Recognition

The aim of this project is to present a new approach for effective recognition and classification of targets irrespective to their position, orientation, and scale. Invariances can be easily incorporated into its structure. A method for invariant feature extraction, under different translation, rotation, and scaling, is discussed and derived. In this method, a feature set is reduced to a mere seven coefficients. These coefficients were then processed in a neural network algorithm for recognition and classification. A standard two-layer feedforward neural network was trained for the classification. Classification is achieved using a multidirectional search algorithm that is more effective than any unidirectional method such as gradient descent, conjugate gradient, or Newton methods. The network is used with an architecture of 7-12-5. Five targets with nine different orientations and scales were used as the training data and the same targets with a new set of orientations and scales served as the testing data. It is shown that the recognition and classification of objects, independent of size and orientation, can be accomplished. The proposed approach has been applied to five different objects and has shown to be very effective, giving classification accuracy up to 100%. See Figure 8 for an illustration of this neural network-based target recognition system.

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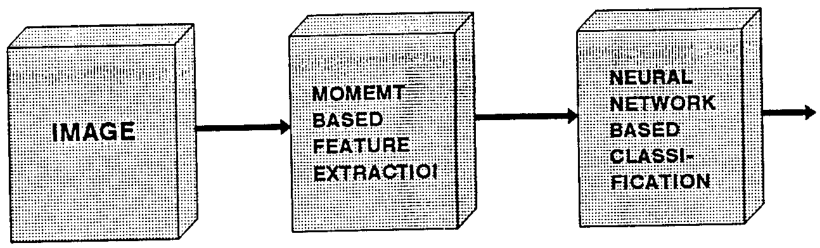


Figure 8: Neural network-based target recognition system.

Electrotechnical Conference, Vol. 1, 1994, pp. 242-245.

6.2 Research Activities of Dr. John G. Kuschewski

Dr. Kuschewski conducted research in the following areas:

6.2.1 Intelligent Aircraft Control System

This project was a spin-off of the CNE, a NASA project subcontracted to CNE by McDonnell Douglas Aerospace Corporation (MDA). The goal of this project was to construct a compact, real-time representation of aerodynamic data that is capable of executing on an on-board aircraft flight computer. Specifically, stability and control derivative terms that are used by the flight control algorithms were to be modeled (represented). Expected to have some kind of neural network architecture, this representation will be constructed off-line and must be very accurate over the entire aircraft operating envelope and be capable of demonstrating correct operation for all inputs. We competed against teams from MDA and NASA to develop the best representation of the data. See Figure 9 for a depiction of the system concept, courtesy of MDA.

We began by considering a group of candidate neural network architectures. We selected the ANFIS (Adaptive Neuro Fuzzy Inference System) architecture because we believed it to have the best potential of all the candidate architectures, if properly trained and optimized, to compactly, very accurately, and in real time represent the MDA aerodynamic data. The ANFIS is an adaptive network that implements a fuzzy inference system (FIS). Thus, unlike a FIS with fixed parameters, an ANFIS is able to adapt its parameters through learning

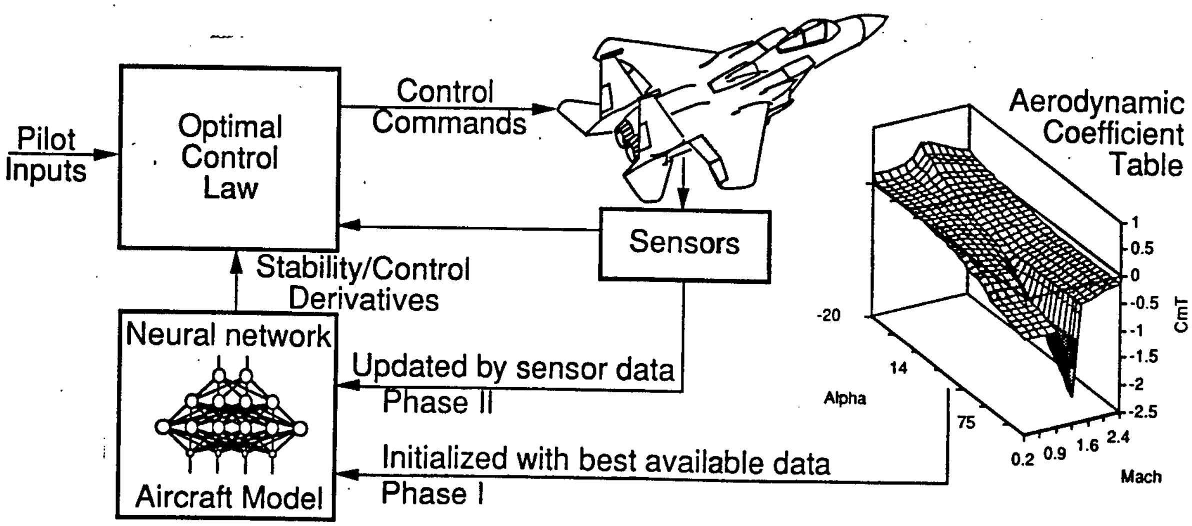


Figure 9: System concept, courtesy of MDA. We created neural networks for Phase I.

to improve its performance. Each data set was modeled by a single ANFIS; the data was used to optimize the fuzzy if-then rules and the membership and crisp function parameters of each ANFIS.

We next developed ANFIS node, computational, and storage requirements to compare ANFIS model requirements to model requirements from the MDA and NASA teams. We then determined an ANFIS model design procedure applicable to all the data sets and developed a method to model the large data sets using multiple ANFIS networks. We were able create models of all small and medium size data sets given to us. However, the large data sets were beyond our ANFIS training capabilities, even on MDA and NASA's advanced computers. CNE team members included Dr. John G. Kuschewski, Dr. Mohan J. Malkani, and Dr. Saleh Zein-Sabatto.

6.2.2 Launch Vehicle Acoustic Suppression Technology

This project was another spin-off of the CNE, a 5 week summer project for HBCU faculty supported by McDonnell Douglas Aerospace Corporation (MDA). The goal of this project was to contribute to the development of a structural/acoustic control strategy for application to launch vehicles. Specifically, the control strategy must reduce the acoustic excitation of the payload enclosed by a rocket payload fairing during rocket lift-off and ascent.

Rocket Payload Fairing A simplified cross-sectional diagram of a rocket payload fairing (without payload) is given in Figure 10. Besides the fairing, the diagram includes a sensor and an actuator (both mounted to the fairing), an interior pressure measurement point, and a disturbance source creating external disturbance pressure waves. During rocket lift-off and ascent, the fairing is subject to a large number of intense structural and acoustic disturbance sources including rocket motor exhaust and aerodynamic shock waves. This

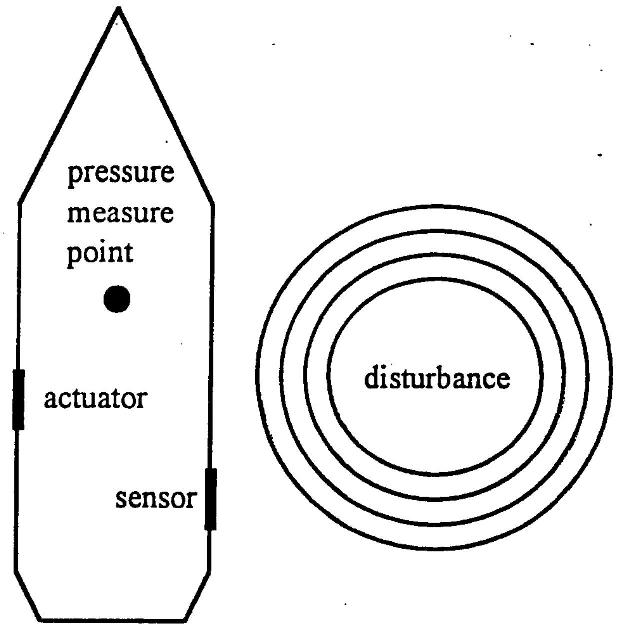


Figure 10: Rocket payload fairing and disturbance source.

combination of sources can cause acoustic pressure levels inside the fairing to reach 130dB, enough to possibly damage sensitive payloads. In addition, the internal acoustic pressure is spatially complex and can vary significantly.

Passive and Active Control Control of fairing interior acoustic pressure is commonly accomplished via passive acoustic blankets that are mounted on the interior of the fairing and surround the payload. Although these one to two inch thick Fiberglas pads provide modest acoustic pressure reduction at higher frequencies ($>$ 250Hz), their use decreases payload weight and volume and can reduce viable payload life. In addition, at lower frequencies thicker blankets are needed, adding significant weight but only slightly reducing acoustic pressure levels. These and other disadvantages of passive acoustic blankets have encouraged the development of lighter weight and smaller volume acoustic pressure control approaches. The advantages of such control approaches, including increased payload weight, volume, and viable life, translate to higher reliability, lower design and testing costs, and lower overall mission costs. Active noise control is one such approach.

Proposed Active Noise Control System A block diagram of the proposed active noise control system is shown in Figure 11. For now, we consider all blocks to be single-input single-output (SISO). In this case, the blocks represent transfer functions. Later on, if needed, we will consider the blocks to be multiple-input multiple-output (MIMO). In that case, the blocks represent matrices of transfer functions. The signals in this control system can be described as follows: "d" is an external disturbance signal, "p" is the pressure at an internal fairing point, "a" is an actuator signal, and "s" is a sensor signal. Based on this description of the signals, the transfer functions (TFs) in this control system can be

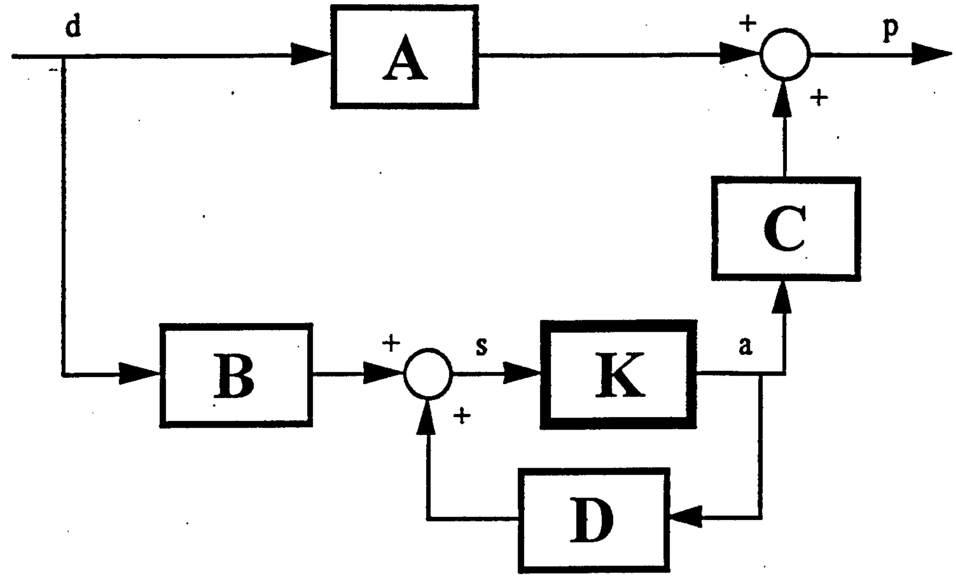


Figure 11: Active noise control system.

described as follows: A is the TF from the disturbance signal to the pressure at an interior fairing point, B is the TF from the disturbance signal to the sensor signal, C is the TF from the actuator signal to the pressure at an interior fairing point, D is the TF from the actuator signal to the sensor signal (a feedback path), and K is the TF from sensor signal to actuator signal (the controller). Once A, B, C, and D are determined via laboratory test and/or computer simulation data, K can be designed.

6.3 Research Activities of Dr. Timothy Teyler

Dr. Teyler conducted research in following areas:

6.3.1 Synaptic Plasticity in the Brain

"Synaptic Plasticity in the Brain" an ONR subcontract from TSU to NEOUCOM 1 Sept 1996 - 31 May 1996. ONR #N00014-92-J-1372. Personnel associated with research related to this sub-project include the following (only S. Morgan was financially supported by the subcontract): T. Teyler, Professor, PI; S. Morgan, Graduate Assistant, NEOUCOM; I. Cavus, Graduate Assistant, NEOUCOM; C. Coussens, Postdoctoral fellow, Univ. Otago, New Zealand; and A. Borroni, Postdoctoral fellow, Univ. Virginia Medical Center

The goals of this subcontract were to assist Dr. Mohan Malkani, Director of the Center for Neural Engineering, and his Research Group, and in particular Dr. Geoff Yuen, by providing services in conducting experiments in support of the development of neural models of hippocampal synaptic plasticity as related to the solution of a spatial navigation problem. Such modeling to incorporate current understanding of the biological properties of the system, in particular the incorporation of two forms of LTP and one form of LTD and the underlying biochemical signal transduction pathways. Specific goals included the

determination of the frequency dependency of the two forms of synaptic plasticity under isolated analysis conditions and determination of the roles of serine-threonine kinases and tyrosine kinases in the two forms of LTP, both using pharmacological enzyme inhibition. In summary, our work has defined the parameters of the frequency-dependent induction of various forms of LTP and has defined the underlying biochemical signal transduction cascades responsible for their expression. Following the listing of personnel associated with the laboratory research directly related to the goals of this project and a listing of the associated publications, I will detail the work accomplished and discuss the implications of this work with respect to the development of biologically constrained hippocampal network models. As this is not intended as a literature review or research report, I will refer to extant work by reference to the author only.

Synaptic plasticity is defined as an enduring change in synaptic efficacy following afferent activation and may be a cellular mechanism important in development and memory. Long-term potentiation, the most commonly studied form of synaptic plasticity, is an enduring increase of synaptic efficacy following high frequency stimulation. A second form of synaptic plasticity, Long-term depression, is a decrease in synaptic efficacy. LTD may be important for reversing LTP or for normalizing synaptic weights. LTP is experimentally induced following high frequency stimulation. LTD is induced following low frequency stimulation. Interestingly, an intermediate tetanus has been shown to result in no long-term modification of synaptic efficacy.

Both LTP and LTD are calcium dependent, requiring increased cytosolic calcium levels and activation of calcium binding proteins for induction and expression. The intracellular application of the calcium chelators, EDTA or BAPTA, block the induction of both LTP and LTD, indicating that all forms are calcium dependent. The increase in intracellular calcium is the first step in the biochemical cascade leading to changes in synaptic plasticity. LTP is dependent on the serine/threonine kinases calcium/calmodulin kinase II (CaMKII), PKC, and PKA. LTD induction is dependent on the activation of the serine/threonine phosphatases 1, 2A and calcineurin (2B).

Protein phosphatases and kinases are known to differ in their affinity for calcium and the intracellular concentration of calcium has been hypothesized by Singer and Teyler to determine whether LTD or LTP is observed. The phosphatase calcineurin B has a higher affinity for calcium than either PKC or CaMKII. Thus, at low levels of intracellular calcium, phosphatases are selectively active. However, as the concentration of calcium increases, the kinases become activated. CaMKII, for instance, displays a concentration-dependent increase in calcium affinity, resulting in one of the highest affinities at high calcium concentrations. Kinase activation also interacts with phosphatases by inhibiting phosphatase activity.

We hypothesized that protein phosphatases and protein kinases are activated by differences in tetanus-induced calcium levels. Thus, synaptic plasticity may be under the bi-directional control of phosphatases (for LTD at low calcium levels) and kinases (for LTP at higher calcium levels), that are of equal and opposite effect at intermediate levels, resulting in no change in synaptic efficacy. During a low frequency tetanus (1-5 Hz), low levels of calcium enter the cell activating calcineurin and phosphatase 1. At higher tetanus frequencies (>10 Hz), higher levels of calcium enter the cell activating CaMKII and PKC. At an intermediate 10 Hz tetanus the intracellular calcium concentration is sufficient to activate phosphatases

and partially activate kinases, inducing effects that are equal and opposite and resulting in no long term change in synaptic function. Application of a broad spectrum kinase inhibitor or decreasing extracellular calcium concentration shifts the balance of phosphatase/kinase activation toward phosphatases, resulting in the 10 Hz tetanus inducing LTD, as shown by Coussens. Conversely, application of a broad spectrum phosphatase inhibitor or increasing the extracellular calcium concentration would shift the balance toward kinases, resulting in LTP.

We have demonstrated that a 10 Hz tetanus does not elicit a long-term change in the pEPSP. Since LTD is a calcium-dependent phenomenon and can be induced with a 3-5 Hz tetanus, and LTP, also calcium-dependent, can be induced at 25+ Hz tetani, the failure to observe any lasting synaptic plasticity at 10 Hz is puzzling since a 10 Hz tetanus is presumably adequate to also increase intracellular calcium. We demonstrated that the 10 Hz tetanus is ineffective because it equally activates the calcium-dependent protein phosphatases necessary for LTD expression and the calcium-dependent protein kinases necessary for LTP expression -effectively cancelling each other. We conclude that either reducing cytosolic calcium (by reducing extracellular calcium concentration) or inhibiting the kinases responsible for LTP expression (with H-7) shifts the balance toward phosphatase activation and results in a 10 Hz tetanus inducing LTD. Conversely, we conclude that either increasing cytosolic calcium (by increasing extracellular calcium concentration) or inhibiting the phosphatases responsible for LTD expression (with tautomycin) shifts the balance in the other direction (toward kinase activation) and results in the 10 Hz tetanus inducing LTP.

Similar results have been reported by other laboratories. Malenka found that LTD can be induced at 25 Hz, a tetanus normally resulting in LTP, when the extracellular concentration of calcium is reduced. We, too, found that with low extracellular calcium concentration a 10 Hz tetanus could induce LTD. Just as LTD can be elicited by a tetanus normally resulting in LTP when the calcium-dependent mechanisms are altered, a low frequency tetanus normally resulting in LTD can elicit LTP in the presence of the phosphatase inhibitor calyculin A. Similarly, Nicoll reported that the bath application of protein phosphatase inhibitors converts a transient increase in evoked EPSCs to a sustained increase. These results are consistent with our findings; inhibition of phosphatase activity, combined with a 10 Hz tetanus, leads to sustained increases in the pEPSP.

These data indicate the LTP frequency curve is modifiable. The curve may be shifted left toward potentiation or right toward depression by manipulating the activation of calcium-dependent mechanisms. At a null tetanus there is an equal but opposite activation of protein serine/threonine kinases and phosphatases. Manipulations resulting in decreased kinase activity, either through reduced calcium entry or inhibition of kinase activity, result in LTD. Manipulations that result in decreased phosphatase activity, either through increased calcium entry or inhibition of serine/threonine phosphatases, result in LTP. Thus, the expression of synaptic plasticity is under bi-directional control of kinase and phosphatase activity -activity, in turn, regulated by changes in cytosolic calcium and induced by frequency-dependent calcium entry as a result of synaptic activity.

In many instances LTP and LTD can be saturated and can be subsequently reversed in the same pathway by different patterns of afferent activity. In the in vitro slice preparation LTP can be prevented and reversed by kinase antagonists, while phosphatase antagonists

prevent and reverse LTD. Thus, LTP and LTD in its simplest form could be a reversible modification of the phosphorylation state of certain proteins directly associated with synaptic transmission, and maintained by persistent enzyme activity. While this may be the case for many instances of LTP/LTD, in some cases these synaptic modifications are irreversible and cannot be altered by afferent activity or enzyme antagonists.

Biochemical studies demonstrate that various enzymes differ in their affinity for calcium and calcium/calmodulin (CaCM). The calcium dependent phosphatase calcineurin (PP2B) has one of the highest affinities for CaCM, and thus is activated at lower levels of calcium than other CaCM dependent enzymes. This is what would be predicted from the studies showing that the selective induction of LTP generally requires conditions that would produce higher calcium than those used for inducing LTD.

The different affinities of PP2 and CaCMKII for CaCM was exploited by Lisman to propose a mechanism for the selective induction of LTP and LTD. His particular model postulates that small increases in calcium will activate PP2B which will then dephosphorylate the PP1 phosphatase inhibitor and thus activate the broad spectrum phosphatase PP1. Higher levels of CaCM are necessary to activate the lower affinity CaCMKII. LTP expression is maintained by the fact that CaCMKII is made persistently active through autophosphorylation. LTD is expressed by decreasing the ability of CaCMKII to autophosphorylate and thereby decreasing it's activity. In this hypothesis PKA and PKC play a modulatory role.

Calcium dependent processes other than the CaCM dependent enzymes have also been implicated in the establishment of synaptic modifications. For instance, PKC antagonists can prevent the induction of LTP. PKC is a calcium activated kinase that has an affinity for calcium that is greatly increased in the presence of DAG. This kinase generally requires higher levels of calcium in order to be activated than that required by the CaCM dependent phosphatase calcineurin and CaCMKII, because the necessary level of free calcium would only be reached after the higher affinity calcium buffering proteins such as calmodulin have been saturated. PKC can phosphorylate both pre- and postsynaptic proteins that would then effect synaptic efficacy. LTD would be expressed when the synaptic proteins are dephosphorylated by CaCM dependent phosphatases.

Protein kinase A, while not directly dependent on calcium, can be modulated by calcium through CaCM sensitive adenylate cyclase and phosphodiesterase. Activation of PKA by noradrenaline and dopamine through G-proteins and adenylate cyclase would then be regulated by calcium. PKA has the ability to increase synaptic efficacy through phosphorylation of AMPAr targeting proteins and phosphorylation of Glu6 subunits. Phosphatases would reverse PKA's effect. PKA activity would be regulated by the cAMP concentration in the cell.

As discussed above and presented in detail by Borroni, calcium influx through NMDA channels, VDCCs, and calcium release from internal stores, results in increases in the intracellular calcium. Calcium can have direct effects or, by binding to calmodulin, indirect effects on synaptic enzymes. With low calcium concentrations, calcineurin (PP2B) is activated. This enzyme will in turn dephosphorylate the PP1 inhibitor. This results in activation of the multisubstrate phosphatase PP1.

As the calcium concentration increases, kinases become activated. Either or both PKC

and CaCMKase display a burst of activity where they phosphorylate various substrates. For the induction and expression of LTP/LTD it is most important that these enzymes act on the proteins directly involved in synaptic transmission. Changes in the balance of intrinsic kinase/phosphatase activity then maintains the new phosphorylation state until subsequent conditioning changes it again by increasing the competing reaction or by decreasing the activity of the enzyme responsible for maintaining the change.

These enzymes also have effects on proteins that are not directly involved in synaptic transmission and thereby effect future induction and/or other reactions that may be useful in consolidating changes. By changing the properties of VDCCs, NMDA channels and GABAergic receptors, as well as modifying the availability of calmodulin and effecting translation and transcription, activation of phosphatases and/or kinases would have the effect of modulating the induction of future synaptic modifications or even consolidating reversible changes. For instance, PKC can phosphorylate the PP1 inhibitor, or a site on PP2A, resulting in decreased phosphatase activity. PKC also indirectly effects the amount of calmodulin that is available to bind to calcium. It does this by phosphorylating certain calmodulin binding proteins in the cytoskeletal matrix which then lowers the binding proteins affinity for calmodulin therebyreleasing calmodulin. Calcium activated enzymes can also change the cytoskeletal structure.

The implication of having a variety of frequency-dependent reversible mechanisms for effecting synaptic transmission is that changes in synaptic strength are not necessarily the result of triggering a single cascade of events. Distinct activation patterns enlist unique enzymatic cascades that are responsible for increases as well as decreases in synaptic weight. Thus, under certain conditions the CNS utilizes different mechanisms for forming mnemonic assemblies. If this is true, then what becomes important is the actual kinetics of the changes induced and expressed by the different enzyme cascades. Assuming that reversible changes are generally induced by modifying the balance of intracellular kinase/phosphatase activity parameters, variables such as baseline kinase and phosphatase activity become critical. The functional implicateions of these discoveries are not yet clear. Among the possibilities that should be considered are the following. LTP may exist in two forms to provide a two-step encoding process wherein the first step is transient and the second permanent. Alternatively, different aspects of experience may be encoded by the two forms. LTD may exist as a mechanism to normalize synaptic weights to avoid the ceiling problem, may exist to increase contrast between regions of dendrite experiencing LTP, or may exist to eliminate old patterns of encoding no longer relevant.

Although our role in this project has been primarily related to the biological end of synaptic plasticity and hippocampal networks, we have made an initial foray into the testing of neural networks using the hippocampal network model developed for navigation modeling by Yuen. Our goal was to add the biologically important phenomena of LTD to the network to determine if this improved the network performance in the navigation model. This work is to be presented in a poster at the 1996 Society for Neuroscience meeting in Washington DC in November, as well as at the Winter Conference on Neural Plasticity in February. The work is currently in progress, preliminary result show promise in terms of enhanced network performance with the incorporation of LTD. The project was initially implemented on Matlab which has proven to be far too slow to be useful as a research tool. The project

will be completed using an implementation written in C by Maida.

The rationale for this approach is that the hippocampus has long been implicated as representing a spatial map of the animal's environment, as evidenced by the well-established existence of hippocampal place cells and the ensemble code for space by Ranck, O'Keefe, McNaughton and others. We utilized Yuen and Spruill's modification of the Burgess navigation model which consists of a five layered network containing 1000 neurons with a feedforward architecture and simple population code for space. The modified model calls for random connectivity of the place cells at the start of training followed by experience-dependent LTP to alter the place cell weights. While this model allows for good navigation in a controlled environment, the initial random connectivity parameter has the potential to provide conflicting navigational signals at times. This is because the random nature of the initialization allows for some units to be heavily weighted. Such units have the capacity of acting as powerful extraneous attractants that interfere with correct goal navigation. Such erroneous signals may be analogous to previously weighted units developed by previous experience with space, so that it was felt desirable to retain the initial randomization parameter. To solve the problem, we are implementing a form of LTD in order to trim out some of the excessive influences of the initial random connectivity. Such an approach is consistent with the known and postulated roles of LTD in functional systems, as discussed by Coussens. Preliminary data indicates that the implementation of LTD has, by trimming initial random associations, enhanced the ability of rats to navigate to the goal.

6.4 Research Activities of Dr. Geoffrey L. Yuen

Dr. Yuen conducted research in the area of Biologically inspired Navigation Neural Networks. Three focus areas have emerged from this effort: [1] Navigation architecture development and simulation, [2] Oscillatory neural networks for spatial information processing, and [3] Hardware implementation of novel architecture/algorithm.

1. *Visualization and simulation software for spatial navigation.* We established a collaboration with Dr. Anthony Maida at University of Southwestern Louisiana (Center for Advanced Computer Studies & Department of Computer Science) to ensure efficient and sustainable software development for new navigation model implementation in the long term. Through Professor Maida's programming efforts, we have currently created a full suite of tools for scientifically visualizing the inner workings of the Burgess model as well as implemented a model introducing Long-Term Depression learning into the Burgess model. Since the simulator is implemented in C++, it offers speed performance not feasible with our earlier Matlab implementation (e.g. one simulation takes about 25 minutes now instead of 9 days as before). Furthermore, a graduate student (Christopher Prince) at USL has developed a Java-based front end to the simulator which allows for platform-independent, multi-institutional interaction via the world wide web (WWW). This allows Dr. Timothy Teyler and Steve Morgan (Ph.D. Candidate) at NEOUCOM in Ohio to participate in the modeling efforts directly and simultaneously. With this simulation/visualization competence in place, we are ready to implement newer designs and architectures for studying spatial navigation quickly

(Yuen et al 1996, Maida et al 1996).

2. *Oscillatory neural networks for spatial information processing.* Through our efforts to develop an oscillatory neural network suitable for use with the hippocampus in navigation (i.e. using frequency dependent learning), we discovered that synchronous firing in the hippocampal CA3 region can be created solely by the well-established long range (~mm) excitatory-to-excitatory connections even in the absence of topographical projections. In particular, neurons that are remote to each other can still be synchronized to fire together rapidly as long as they are connected by excitatory-to-excitatory connections. This appears to be, to our knowledge, the first model describing the possibility of using synchrony and asynchrony to process information which does not require the use of topographical mapping (where neighboring inputs are projected to neighboring neurons). Most current models of synchronous firing in neurons are based on the visual system and thus requires topographical projections to operate. We expect this new finding to shed light on how ensemble or population computation can be carried out in the hippocampus especially with respect to spatial navigation, where a population code predicting current or next position of the animal has been demonstrated (Wilson and McNaughton 1993).

3. *New spatial navigation architecture.* An alternative architecture to Neil Burgess's hippocampal navigational model has been devised, based on an ethological analysis of the problem of returning to desirable goal locations. This new architecture has the following major advantages over Burgess's model (Burgess et al 1994): [a] Incorporates more realistic connectivity patterns in the hippocampus. [b] More congruent with the multiplicity of long-term synaptic modification rules observed in this part of the brain and [c] Addresses the question of how temporally delayed goal location information can be fed back to selectively reinforce previously acquired information. For example, during normal exploration, a basically feedforward architecture and standard NMDA-LTP is in effect; however, during goal encounters (or noxious stimulus), CA3 is also recruited in a recurrent fashion to engage in the learning of these important locations using VDCC-LTP. This new model is currently being implemented in Dr. Maida's simulator described above.

6.4.1 Visualization/Simulator Software Development

Our last simulator developed in Matlab was abandoned due to its slow speed (e.g. took 9 days to complete one training trial on a Pentium P5-100 MHz PC) and the lack of visualization graphics for troubleshooting and facilitating understanding. It was also concluded that this simulator cannot support rapid code and model development. The current simulator is developed in C++ (on a Powermac using Metrowerks Codewarrior) in collaboration with Dr. Anthony Maida (Professor of Computer Science, University of Southwestern Louisiana, Lafayette, LA). A picture of the graphical user interface of this simulator is attached with this report. A dynamic demonstration of the rat's navigation is also available at WWW address `http://acad.tnstate.edu/~eecneweb/cne/research/bionav/bionav.htm`. In addition to the performance and developmental advantages, improved features not available with the

earlier version include:

1. Visualization of cell firing and synaptic modification in all layers during navigation (refer to simulator figure): cell activations (beige-checkered panels on lower half), synaptic weights (black panels with green gridlines).

2. Simultaneous display of place/subicular/goal cells receptive fields before and after learning: (large, beige panels on upper left). For example, a second illustration shows two side-by-side comparisons of 49 place fields (I) before, (II) after 300 second LTP and (III) LTP/LTD training.

3. Java front-end permitting collaboration via WWW between USL, TSU and NEOUCOM (being developed by Christopher Prince, Ph.D. candidate in psychology/computer science at USL).

4. Multiple learning rules supported: this includes LTP as well as LTD to any selected layer(s).

6.4.2 Oscillatory Neural Network for Spatial Information Processing

The hippocampus is well-known for its various oscillatory electrical rhythms, apparently much more prevalent than the visual cortex (Gray review 1994). In an attempt to create an oscillatory neural network to study the effects of frequency-dependent learning, we modified a model developed by Konig-Schillen for the visual cortex to study hippocampal spatial information processing. This is possible because the connectivity for the two brain regions are similar except for two main connections missing in the visual cortex: next neighbor, short range inhibitory-to-excitatory connections and long range excitatory-to-excitatory. Thus, the oscillatory properties for CA1 can be studied by simply adding the former while CA3 can be studied by adding both types of connections. The most important conclusion emerging from this studies is that synchrony and desynchrony can still be maintained in the hippocampal CA3 region despite the nontopographical nature of place cells with respect to the input space. This is significant for a number of reasons: [1] Most models of synchrony/desynchrony processing in the brain to date relied on topographical maps such as that found in the visual cortex. [2] The reliance solely on long-range excitatory-to-excitatory connections implies that cells can be recruited into cell assemblies even if they are physically far apart (i.e. not neighbors). [3] The ability for groups of hippocampal neurons to work synchronously is extremely important for spatial information processing as a population code for current/predicted spatial location based on place cells has been demonstrated experimentally (Wilson and McNaughton 1993). Our finding can provide a mechanism by which the hypothetical ensemble computation proposed by Wilson and McNaughton can be implemented in the neural hardware.

Oscillatory Properties of the CA1 Region The CA1 region of the hippocampus was modeled with basic oscillatory elements with excitatory to inhibitory cross connections as shown in Figure 12. The addition of excitatory to inhibitory connections improves the overall

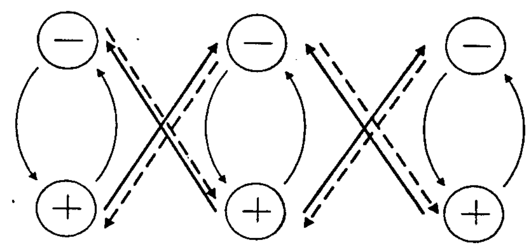


Figure 12: Network representation of hippocampal CA1 region.

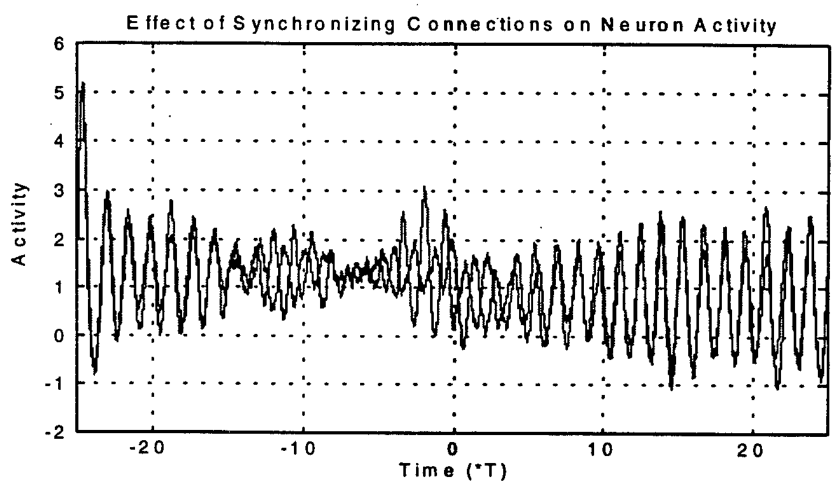


Figure 13: Neuronal activity for neurons with CA1 connectivity showing neurons ability to synchronize.

synchronizing capability of the network. The results of forming these connections on a 5×5 layer of neurons are shown in Figure 13. The network synchronizes within a few cycles of the connections being applied. This type of network does not desynchronize, rather the inhibitory to excitatory connections increase its ability to synchronize in comparison to the original network. Compare to its parent visual cortical network, this CA1 network achieves synchrony is less time and with greater accuracy even in the presence of noise. However, given the circuitry above, we were unable to desychronize network into separate populations after synchronization.

Oscillatory Properties of the CA3 Region The CA3 region of the brain can be modeled as an extension of the original Konig-Schillen network by adding next-neighbor, inhibitory-to-excitatory as well as long-range, excitatory-to-excitatory connections (see Figure 14). The former type of connection provide the same synchronization capabilities as in the CA1-like network while the excitatory to excitatory connections provide a mechanism for desynchronization.

In pilot simulations, we challenged the network with orientation-specific stimulus as those used in the visual cortex with a chain of eight oscillators with CA3-like connectivity. The network was able to perform stimulus-dependent segregation and segmentation tasks. The

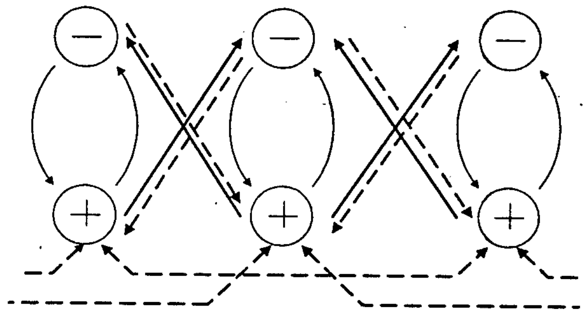


Figure 14: Network representation of CA3 region of hippocampus.

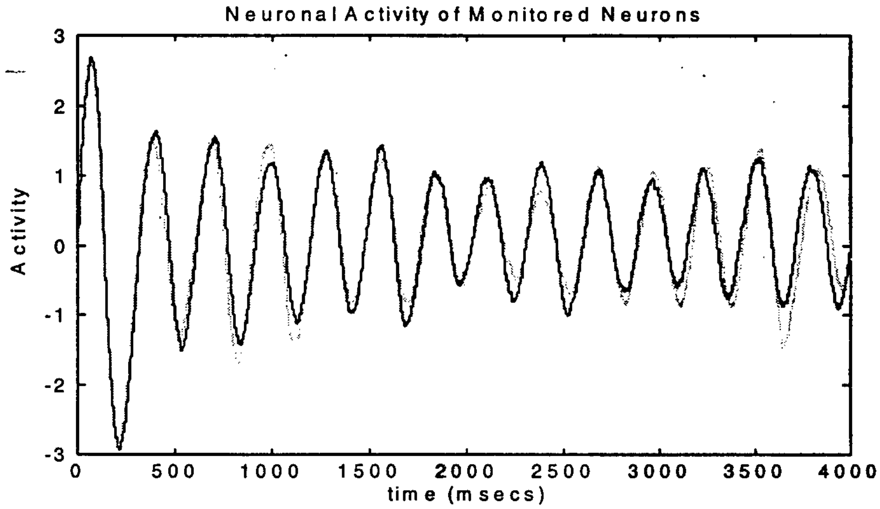
results as shown in Figure 15 were comparable to the those of the visual network. Since the CA3 region has connections to the CA1 region which allow synchronized oscillations in the CA1 by stimulation of the CA3, desynchronization in CA3 can also provide a trigger for CA1 to be desynchronized (Buzaki 1989).

Application to Spatial Information Processing

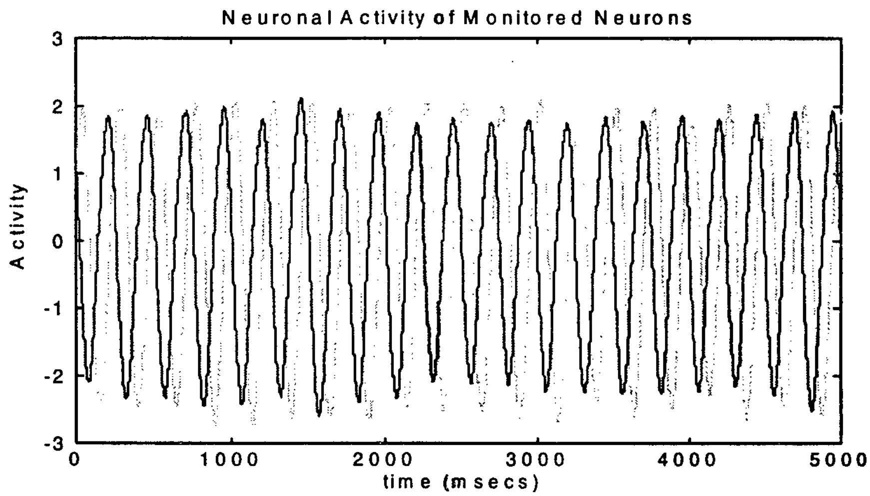
CA1 region Single cell recording has shown that as an animal moves from one location to another, different neurons in the hippocampus respond depending on the current position. This type of response over an environment can be used map for planning locomotion. However, the neurons which respond at neighboring locations can be widely distributed within the hippocampus, thus giving rise to a non-topographical spatial mapping. It is not clear how such a mapping can be used effectively for collectively computation or navigation. We shown here that it is possible to use the familiar synchrony/desynchrony mechanisms to perform population encoding. In fact, even neurons that are far apart can be synchronized together into a synchronously firing group provided they have the excitatory-to-excitatory connections with proper delays.

A 5×5 layer of oscillators with CA1 connectivity is used to represent location selective cells in a rectangular arena. Each oscillators responds to a 9cm by 9cm area in the arena. Figure 16 shows the firing response of an oscillator to the 9cm by 9cm area it represents. The tuning of the cell to the preferred location is a gaussian distribution which is a function of the x and y coordinates for area covered by the cell. Maximum response occurs at x and y coordinates located in the center of the 9cm by 9cm area. The area represented by each cell may correspond to a separate area in the arena or the area covered by two or more cells may overlap.

The cell at location (5,5) in the network is arbitrarily chosen. An input to indicate the mouse's position at its preferred location to achieve maximum firing response is used as bias current to this cell. A second neighbor cell (3,3) is connected via an excitatory to excitatory connection. Our results indicate that the two cells' ability to phase-lock is simply a function of the delay time of the excitatory-to-excitatory connection. The two cells oscillate in synchrony at for delay times of 25, 50, 75 and 100ms. Figure 17 shows a random sampling of neuronal activity for the second cell with various delay times. The delay shifts the



Neurons synchronize with assembly closest to preferred orientation



Neurons segregate to synchronize with closest preferred orientation

Figure 15: Stimulus-dependent segregation of neuronal assemblies.

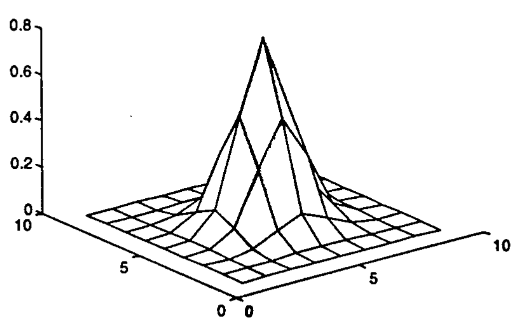


Figure 16: Firing response of cell to 9cm by 9cm area.

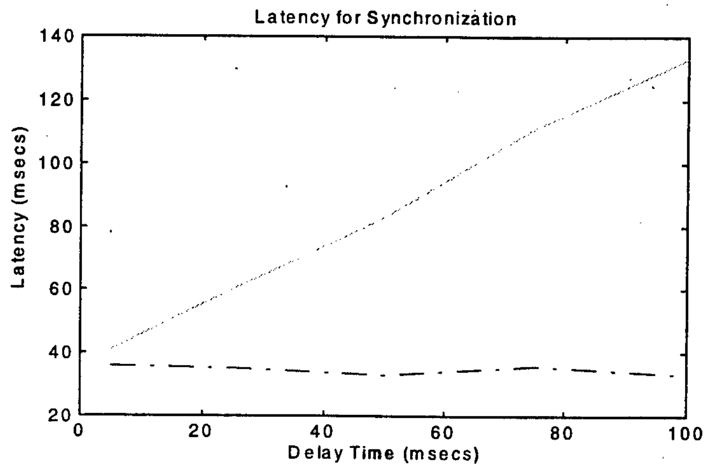


Figure 17: Latency times for synchronizing delay times actual (dotted line) and minus delay period (solid line).

beginning of the oscillations so that the second cell will achieve synchrony with the first only at certain times/periods. It can be assumed that this behavior is cyclic continue for delay times greater than 100ms at the same interval. Varying the synaptic weight strength and bias current input to the second cell do not affect the synchrony. Since input to the second cell constitutes overlap in the environment, the implications of this result are significant. It implies that even if cells represent area that are physically close, they require excitatory to excitatory connection in order to synchronize. Thus stimulus-dependent segregation can not be accomplished without these connections. Among cells that have the correct delay times for synchrony, the times required to phase-lock (total time for synchrony minus conduction delay time) are similar. The latency period before synchronization is approximately 35ms (dotted line in Figure 17).

CA3 region The simulation study was extended to a 11 $\times$ 11 network of oscillators connected with CA3-like connectivity. The center oscillator was given input to invoke a maximum firing response. When connected with neighboring oscillators 2, 3 and 4 oscillators away, the above described time delay requirement for synchrony was maintained. The oscillators synchronized with delay times of 25, 50, 75 and 100ms. The latency periods were also the same with average time being approximately 35ms.

Lastly, the network was modified and given random excitatory to excitatory connections from the center cell to randomly chosen and spaced cells in the network. Similar results were obtained: the network failed to synchronize at any delay times other than 25, 50, 75 and 100ms. The insensitivity of the pattern of synchronization to changes in the connectivity of the network further substantiates that this pattern is only a function of the delay time. More significantly, any remote neuron with the proper delay time constants can be recruited into synchrony with any other neuron with which it receives an excitatory-to-excitatory connection!

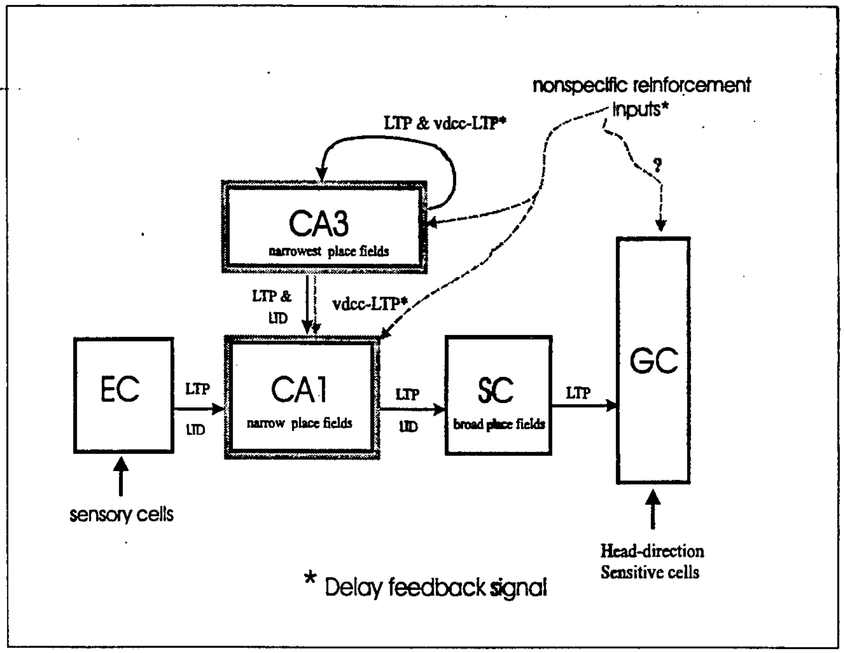


Figure 18: A new hippocampal navigation architecture that may solve the credit assignment problem using frequency-dependent learning. The subcircuit related to delayed reinforcement feedback and VDCC-LTP is shaded.

6.4.3 A New Navigation Model

A new navigation model has been designed which take into account a number of issues implicit in the navigation to goal problem. The issues are described briefly below after a description of the new model proposed here.

Working Hypothesis of The New Navigation Model A reinforcement-learning like mechanism exploiting frequency-dependent learning might be used by the hippocampus to solve the temporal credit assignment problem for navigational guidance. In particular, CA3 neurons train CA1 neurons through VDCC-LTP during positive reinforcement when goals are encountered. During exploration, NMDA-LTP and NMDA-LTD combined to create suitable place-field representations and build basic acquaintance with the environment.

Picture of Operation The proposed architecture is a six-layer recurrent architecture that [1] addresses the issue of delay feedback of the goal location information, [2] incorporates representations for place-cell spatial responsiveness and population coding of space as well as [3] is consistent with current hippocampal connectivity and physiology relevant to navigation. During exploration, the network operates in a primarily feedforward mode in which both the CA1 and CA3 regions acquire information about the arena by building place-field representations, using a combination of NMDA-based LTP and LTD mechanisms. When a goal is encountered, nonspecific reinforcement signals are turned on (shaded arrows in Figure 18), causing the network to go into a high gain stage using VDCC-LTP learning to

enhance connectivity between CA3 and CA1, as well as recurrent connectivity within CA3.

Justification of Basic Principles

Dealing with delay feedback information of targets and obstacles: reinforcement learning approaches may solve the temporal credit assignment problem for navigation Place cells and population coding for space can readily provide information about where an animal or robot might be in space. However, this type of information does not indicate where desirable locations are and how to get to these locations directly. Three necessary but distinct questions implied in any navigation task are: [1] What is one's current location? [2] Where are the desirable locations to reach? and [3] How does one reach those locations?

While place-cells and population coding of space can readily address the first question, it is quite likely that they are also closely tied to the computation required to answer [2] and [3]. Since the information needed to answer question [2], "Where the desirable locations are?" does not become available until the end of an exploration period, when the goal is reached, this late arriving goal information must be integrated back with previously acquired information about the environment during exploration. Otherwise, the animal cannot benefit from the exploration phase and improves its chances to return to the goal more robustly. Another way to describe this problem is that, before the goal is encountered, all locations are neutral with respect to their value to be returned to in the future. After goal encounter(s), however, goal locations are biased by the nature of the experience (positive or negative) for future return or avoidance. This calls for a mechanism by which late-arriving value information about locations can be linked with place-fields or population codes formed during exploration.

Though faithful to hippocampal circuitry, our proposed model is similar to the architecture of the original Adaptive Critic/Associative Search Element network originally proposed by Barto, Sutton and Anderson to solve their credit assignment problem in the inverted pendulum balancing problem (see Barto, Anderson and Sutton 1983, Barto, Sutton and Watkins 1989). Three aspects of this picture of operation are especially similar to the workings of their reinforcment neural networks: [1] Delayed reinforcement feedback: nonspecific cholinergic inputs and CA3 burst-output training signal to CA1 are both delayed and discrete as in the classical Adpative Critic/Associative Search Element reinforcement learning architecture; biochemical treatments that interfere with the septo-cholinergic system also affects spatial learning abilities (Blokland and Jolles 1993, Nilsson and Gage 1991, Kuhar 1975). [2] Eligibility: NMDA-receptors on CA1 dendrites have slow time course which allow recent occurring synaptic events to be tracked (cf. grayed eligibility synapses in Figure 18 and Figure 19); both the Adaptive Critic and the Associative Search Element have synapses that have exponentially decaying eligibility traces (Barto, Anderson and Sutton 1983). [3] Quantization of input space: place-cells are basically similar the "boxes" in the classical architecture as they both partition the input space for later assignment of credit or value.

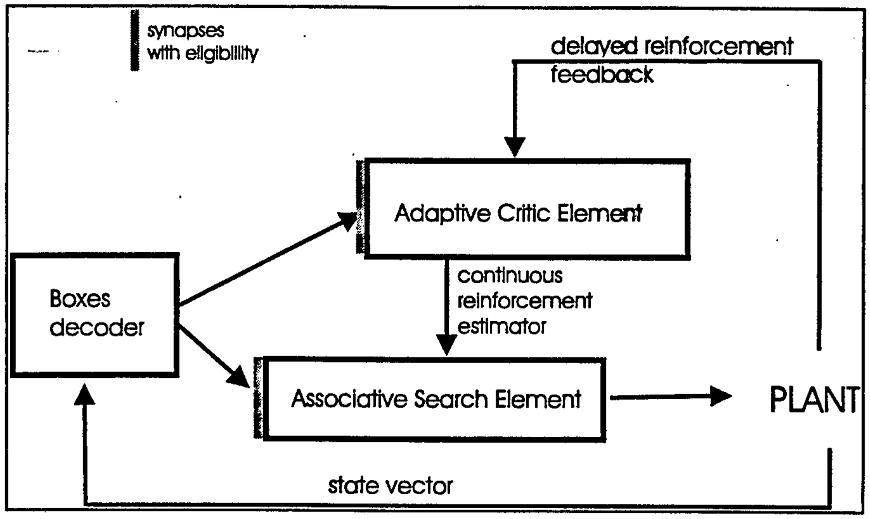


Figure 19: Basic reinforcement learning architecture (After Barto, Anderson and Sutton 1983).

Incorporates representations for Place-cell spatial responsiveness and population coding of space Recent studies of the effect of exploration and LTP on the ensemble properties of place cells suggest that CA3 neurons might generate a predictive code for future locations (Blum and Abbott 1995, Wilson and McNaughton 1993, Korol et al 1993). Navigation is envisioned to proceed by using the difference between the predicted location vector (computed by CA3 neurons) and the current location vector (computed by CA1 neurons). While this scenario answers questions [1] and [3] in the previous section, it does not address question [2]: "Where is a desirable target location?". We suggest that the VDCC-LTP phase of frequency-dependent learning can solve this problem by providing the necessary signals from nonspecific connections and a well-known process of training of CA1 by CA3 neurons (Buzsaki 1989). From this perspective, place cell representations of current locations are built among CA1 neurons along with predictions of future locations among CA3 neurons during normal exploration using NMDA-LTP and LTD. Upon reaching a goal or obstacle, however, nonspecific reinforcing cholingergic and other inputs enhance general excitability of CA3 and CA1 neurons, leading to burst firing and gamma rhythms in the CA3 layer. The latter then fire at high-frequency to trigger VDCC-LTP to "train" appropriate (i.e. location-predictive) information into CA1 neurons.

Biologically realizable synaptic connectivity: anatomical connectivity and synaptic physiology As is evident in the description above, we do not impose our interpretation upon the hippocampal circuitry but instead provide a framework to integrate many different aspects of hippocampal anatomy and organization. In fact, it is remarkable that the anatomy and synaptic physiology is completely consistent with a "reinforcement-like" type of solution of the delay reward feedback problem (cf. the reinforcement architecture proposed by Barto, Anderson and Sutton with the new navigation architecture).

Three attractive features of the proposed architecture are immediately apparent: [1]

Efficiency: the ability to generalize about future locations due to the predictive location map created among CA3 neurons; [2] Amplification of location-specific reinforcement information: while the cholingergic inputs are nonspecific and active upon goal encounters, the activated CA3 neurons can then provide more informative location-specific training to CA1 neurons; [3] Visualization of population vector interaction and transformation: since both CA3 and CA1 are currently believed to generate ensemble codes (or population vectors), this architecture allow one to study the interaction as well as the subsequent transformation of these vectors in a real world task. This model is currently being implemented using Professor Maida's simulator.

6.4.4 Hardware Implementation of Novel Architecture/Algorithm

We have acquired a mobile robot platform to implement in hardware our biological based navigation algorithm/architecture. This project will not only force us to ensure our new architectures are deployable in real time as well as provide a platform to focus our development with respect to realistic performance strategies or tactics. For example, we hope to address the problems of moving targets, obstacles and/or cues as they relate to the computation of optimal navigation trajectories when both the software and hardware components are integrated. These latter problems are of tremendous interest in industry as well as military applications.

6.5 Research Activities of Dr. Saleh Zein-Sabatto

Dr. Zein-Sabatto conducted research in following areas:

6.5.1 Neural Network Applications in Intelligent Flight Control Systems

The model helicopter XL-30 purchased in the summer of 1994, is assembled, tested and now is operational. A microcontroller system was designed built and tested on the helicopter. The microcontroller system consists of one master Stamp microcontroller for communication and five other Stamp microcontrollers for actuator controls. The master microcontroller provides communication between a host computer and the actuator microcontrollers. The master microcontroller receives flight commands from the PC through its keyboard and sends them to the proper microcontroller connected to the target actuator. Figure 20 shows the schematic layout of the microcontroller system architecture. The next step for completing the control system is to equip the helicopter with sensor for feedback signals. Currently, the helicopter is equipped with one gyroscope providing information about the yaw axis of the helicopter. Two more gyros for the pitch and roll will be added to the helicopter. In addition, two pots will be added to the stand to provide information about the helicopter altitude and position in the horizontal plane. The established feedback signals will be measured and fed back to the PC through a additional stamp microcontroller where it will be used by an intelligent neurocontroller. The current hardware setup of the helicopter and its PC interface is shown in Figure 21.

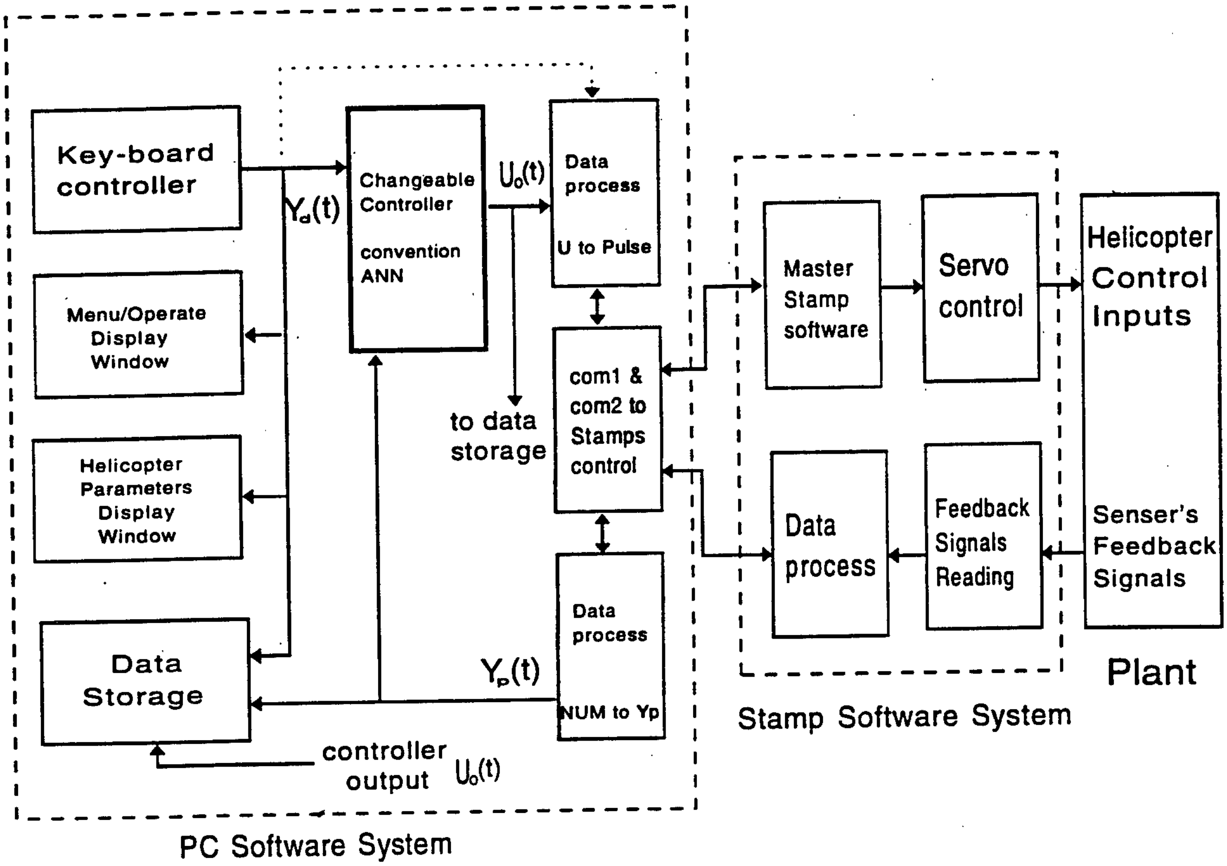


Figure 20: Schematic layout of the microcontroller system architecture.

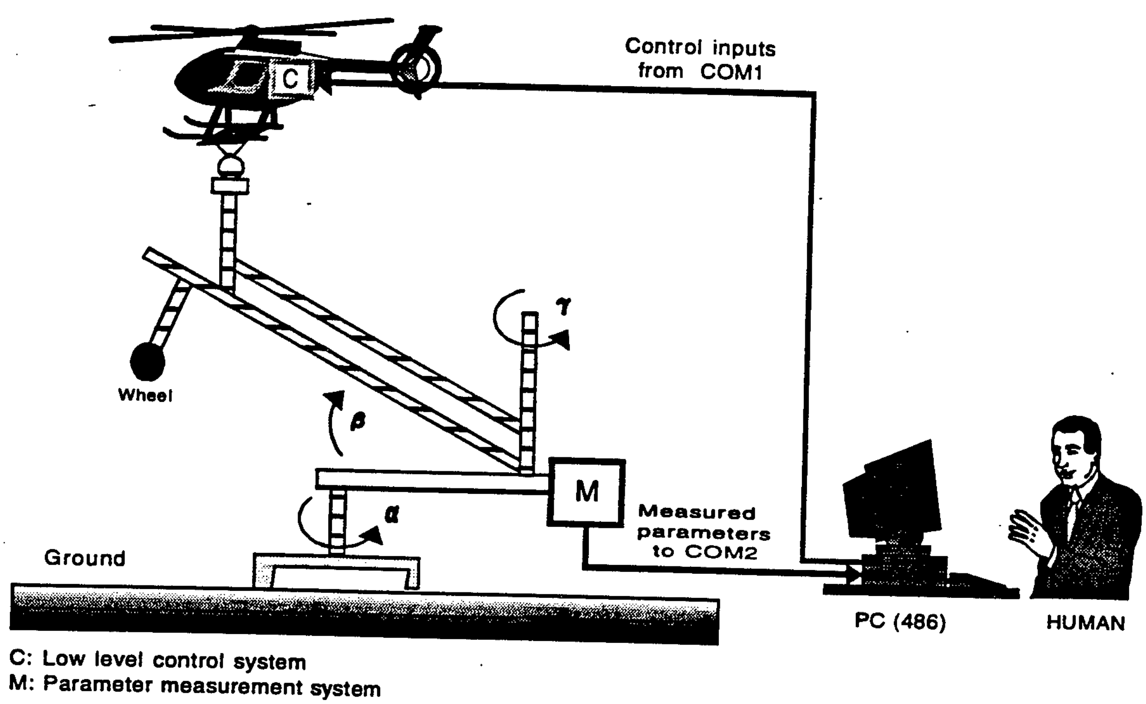


Figure 21: Helicopter hardware and PC interface.

6.5.2 Intelligent Helicopter Altitude Control

A helicopter is a complex nonlinear dynamic system. Thus, to find an accurate analytical mathematical model for a helicopter is very difficult or even impossible. The conventional methods (classical or modern) can not be efficiently used in a controller design procedure without an accurate mathematical models of the plant. In this research, a new approach is used to design a controller for a complex nonlinear plant like a helicopter without an accurate mathematical model. We call this approach an intelligent approach. Using this new approach, we will design an intelligent helicopter altitude controller.

The new approach starts from the helicopter flight experimental data, then trains a neural model to learn the behavior of the helicopter. Based on the neural model and the human knowledge, we use genetic algorithm, fuzzy logic control, and adaptive control methods to design an Intelligent Helicopter Altitude Controller. The block diagram of this approach is shown in Figure 22.

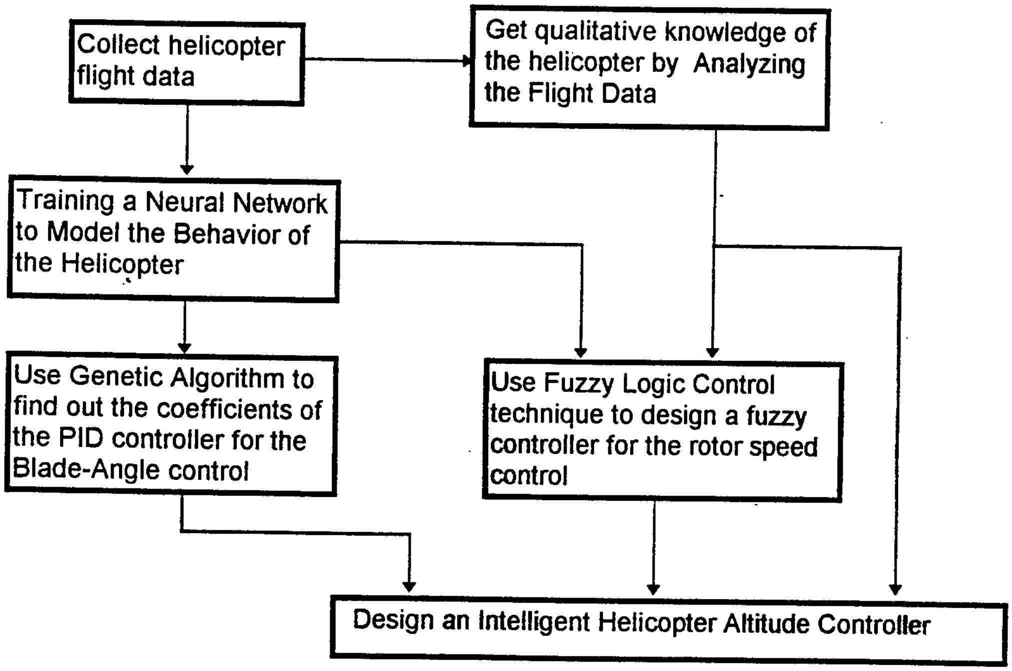


Figure 22: The flowchart of the new approach.

The altitude of the helicopter is controlled by the main rotator speed and the blade angle of the main rotator. We collected helicopter flight data from the helicopter flight experiment system and attempted to model this relationship between the altitude and the inputs, the blade angle and the rotor speed.

In an off-line controller design strategy, a plant model is usually required. Feedforward neural networks can, of course, be viewed as nonlinear input-output models. Researchers working in the area of system modeling and identification have been actively investigating various nonlinear models. In our research, a multi-layer feedforward network structure and an error back-propagation training algorithm are used to train a neural network to learn the dynamic characteristics of helicopter flight from experimental helicopter flight data.

From the experiment data (Figure 23), it can be seen that the altitude H is not only determined by current data of the rotator speed control input and blade angle control input, but also determined by the previous values of these parameters, assuming that the altitude is a function of the current and the previous data of the rotator speed, blade angle and altitude.

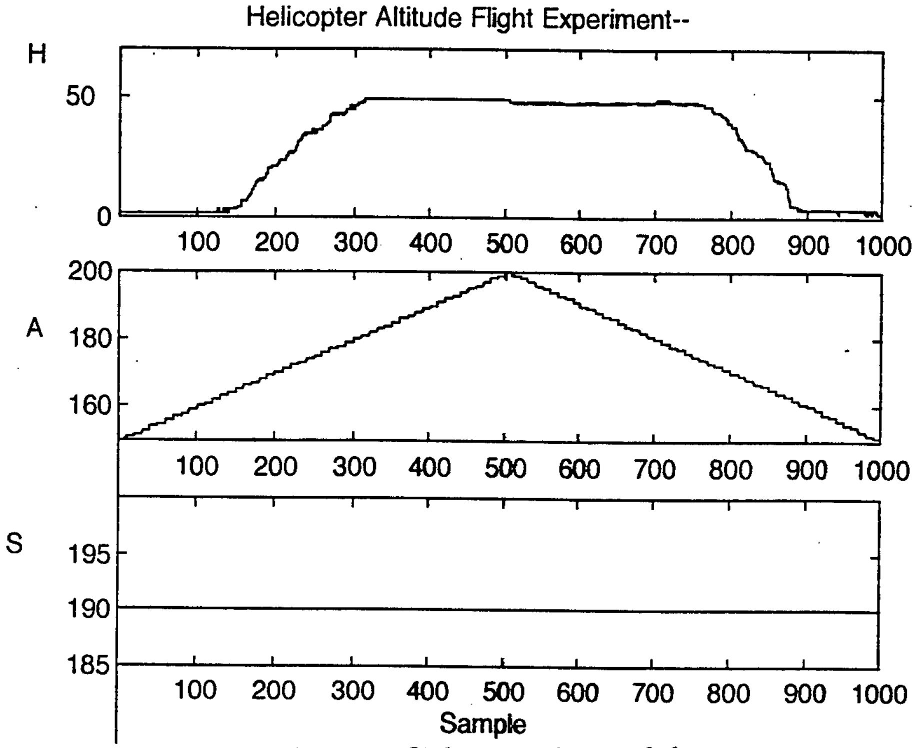


Figure 23: Helicopter flight experimental data.

We can write the relationship between the inputs and the altitude as

$$H_{k+1} = F(H_k, H_{k-1}, H_{k-2}, S_k, S_{k-1}, S_{k-2}, A_k, A_{k-1}, A_{k-2}),$$

where H_{k+1} is the next altitude, H_k, H_{k-1}, and H_{k-2} are the current and previous altitudes, S_k, S_{k-1}, and S_{k-2} are the current and previous rotator speed control inputs, and A_k, A_{k-1}, and A_{k-2} are the current and previous blade angle control inputs.

A three-layer feedforward neural network is trained to model the function above. The real helicopter flight data and the neural model output are shown in Figure 24.

Based on this neural model, we plan to use a genetic algorithm to find a PID controller for the controlling the rotator blade angle. Then, based on the human knowledge about the relationship between the helicopter altitude and the rotor speed and blade angle inputs, a fuzzy logic rotor speed controller will be designed. Finally, the PID controller and the Fuzzy controller will be combined together to form an Intelligent Helicopter Altitude Controller. This controller is shown in Figure 25.

6.5.3 Intelligent Neurosystem for Aircraft Failure Identification

In defining a control system as being "intelligent", a key goal is the achievement of high performance coupled with dependability, availability, and automation of maintenance pro-

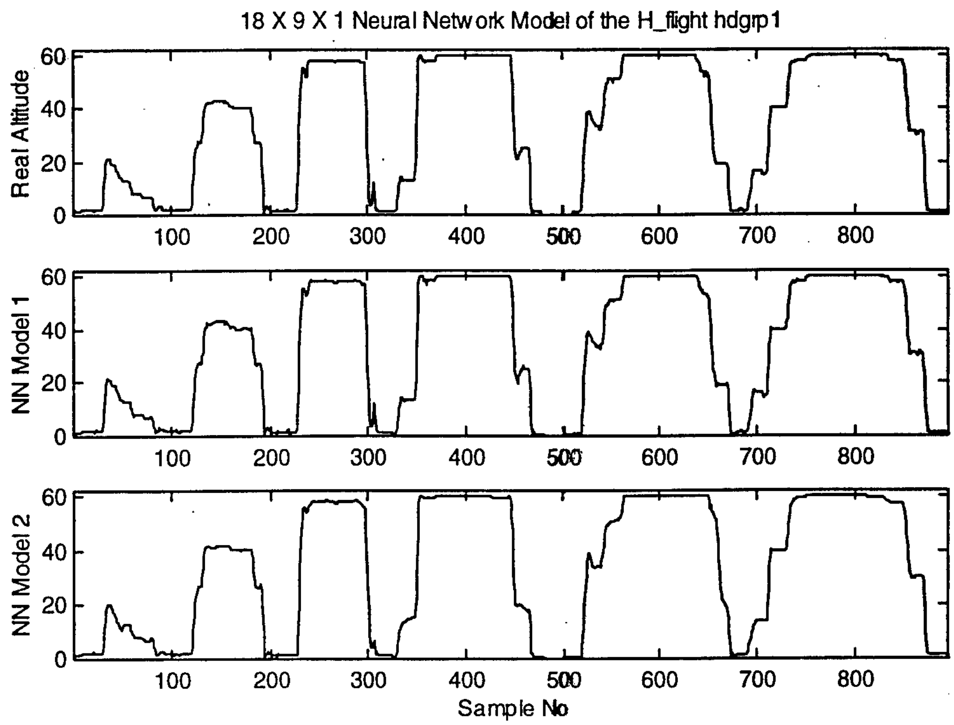


Figure 24: The output of the neural models and the real data.

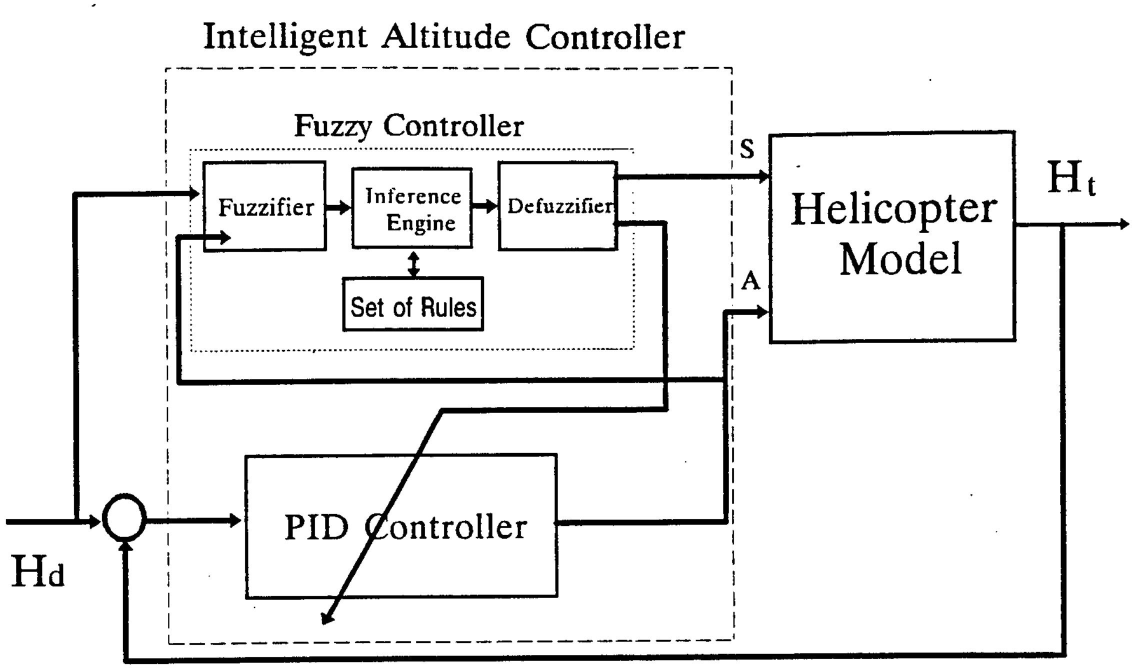


Figure 25: Intelligent helicopter altitude controller.

cedures. Qualitatively, a system which includes the ability to sense its environment, process the information to reduce uncertainty, plan, generate and execute control action in adverse situations that cause variations in system parameters and input signals, constitutes and intelligent system. In the design of intelligent and autonomous control systems, fault diagnosis and accommodation (FDA) is fast becoming an issue of primary significance. It provides the prerequisites for increased reliability, safety and systems availability, automation of inspection procedures, minimization of maintenance activities and costs, and the enhancement of system performance via early detection and correction of incipient faults. Failure detection and accommodation systems are, therefore, attracting attention in a wide range of system engineering projects, including aircraft and propulsion systems, power plants, chemical processes, etc.

Failure diagnosis can be categorized into two groups. The first makes use of plant models, and are referred to as model based methods. The second does not make use of plant models, anre are referred to as model free methods. The goal of this research is to use a model based method with a neural network to develop an intelligent neuro-system for aircraft failure identification and use a classical control method to design a combination feedback controller that is suitable for system recovery when an unknown failure occurs. The schematic diagram of the developed intelligent system is shown in This controller is shown in Figure 26.

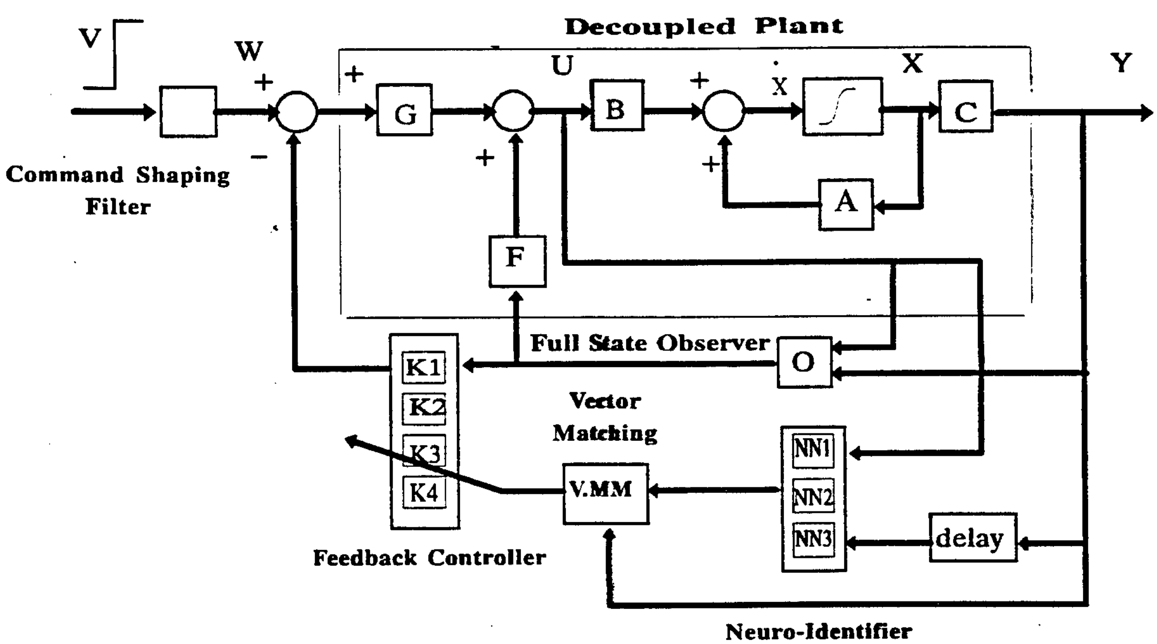


Figure 26: Intelligent controller for complex dynamic system.

7 Intelligent Robot Navigation Platform

7.1 Project Goal

Implement intelligent navigation schemes in a mobile robot system.

7.2 Accomplishments

After reviewing mobile robot systems from multiple vendors, we found only three vendors that offered systems that addressed our research project requirements: Real World Interface, Inc. (RWI), Nomadic Technologies, Inc., and Transitions Research Corporation (TRC). Upon further review, we found that only the B14 mobile robot system from RWI was able to meet our project requirements and our budget. A purchase requisition has been prepared and submitted and is currently in process; we expect to receive the robot system in early summer 1996.

7.3 Selection Criteria

- Under Budget
- Open and Extendable System Software
- High Performance System Hardware
- Suitable for Navigation Research Tasks

7.4 Mobile Robot System

The RWI B14 mobile robot system we ordered consists of the following components:

- Synchronous Drive Base with Tactile "Smart Panels"
- Enclosure with Tactile and Sonar "Smart Panels"
- Dual Pentium Onboard Personal Computer (PC) (133 MHz) with 32MB RAM and a shock mounted 1.2GB Hard Drive running the Linux Operating System and RWI Robotics Application Interface (RAI) Software
- Regulated Switching Power Station
- PCI Frame Grabber Video Card
- VPC-920 Color CCD Camera
- ComRAD RS-232 Serial Radio Link

In addition, a Desktop PC "Base Station" (also running Linux) communicates with the Onboard PC via the radio link. Some of these components are depicted in Figure 27.

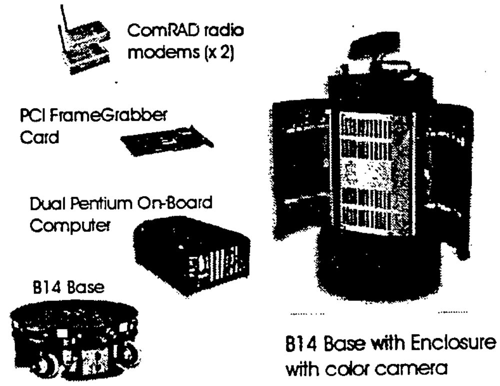


Figure 27: Robot system component montage (courtesy RWI).

7.5 Robot System Operation

The Onboard PC, which hosts the RAI robotics systems client libraries and robot server software, is the central component of the entire mobile robot system. It takes low-level inputs from the tactile and sonar sensors and color camera and high-level inputs from the base station. It then processes these inputs to generate outputs that are sent to the base (movement commands) and the base station (telemetry).

7.6 Application

We will use the mobile robot system as a implementation platform for intelligent navigation schemes.

8 Faculty Publications

The faculty publications increased significantly over the first and second year's list as shown below:

8.1 Book Chapters

1. A. Borroni, C. Coussens, and T. J. Teyler, "Receptor regulation in synaptic plasticity," In C. Shaw (Ed.) Receptor Dynamics in Neural Development, CRC Press, 1995, pp. 239-252.

2. G. L. F. Yuen, "Response synchrony, APG theory and motor control," In D. Levine, T. Shirey, and V. Brown, (Ed.) Oscillations in Neural Systems, Lawrence Erlbaum Associates, 1996, in press.

8.2 Refereed Papers

1. M. Essawy and M. Bodruzzaman, "Iterative prediction of chaotic time-series using recurrent neural network," Accepted to ANNIE '96, St. Louis, MO, November 1996.

2. M. Bodruzzaman and M. Essawy, "Neural network-based modeling of dynamical systems," Submitted to the Journal of Chaos, Solitons and Fractals, Pergamon Press, May 1996.

3. S. Ramamurthy, M. Bodruzzaman, and G. L. F. Yuen, "Neural Network and Moment Based Target Recognition and Classification," To be submitted to 1996 Southeastcon, Tampa, FL, April 11-14, 1996.

4. W. R. Hwang, S. Zein-Sabatto, and J. G. Kuschewski, "Fuzzy Controller Design Using Genetic Algorithms," Submitted to the IEEE International Symposium on Intelligent Control, December 1995.

5. W. R. Hwang, S. Zein-Sabatto, and J. G. Kuschewski, "Model reference adaptive fuzzy controller design using genetic algorithms," Accepted to ANNIE '96, St. Louis, MO, November 1996.

6. C. Coussens and T. J. Teyler, "Balance of protein kinase and phosphatase activation following a 10 Hz tetanus," *1995 Australasian Winter Conference on Brain Research*, Queenstown, New Zealand, August 1995.

7. T. J. Teyler, I. Cavus, and C. Coussens, "Synaptic plasticity in the hippocampal slice: functional consequences," *J. Neurosci. Meth.*, 1995, 59, pp. 11-17.

8. S. L. Morgan, J. Spruill, G. Yuen, and T. J. Teyler, "Long term depression and navigation: A simulation model," *Soc. Neuroscience. Abs.*, 1996.

9. I. Cavus and T. J. Teyler, "Two forms of LTP activate different signal transduction pathways," *J. Neurophysiology, in press*, 1996.

10. S. L. Morgan, G. Yuen, and T. J. Teyler, "Frequency-dependent regulation of long-term potentiation," Manuscript in preparation, 1996.

11. G. L. Yuen, P. E. Hockberger, and J. C. Houk, "Bistability in cerebellar purkinje cell dendrites based on high-threshold calcium and delayed-rectifier potassium channels," *Biological Cybernetics, in press*, 1995.

12. G. L. F. Yuen and D. M. Durand, "Ethanol suppresses NMDA-mediated synaptic response in hippocampal granule cells," Submitted to the Journal of Neurophysiology, July 1996.

13. S. Zein-Sabatto, O. Al-Smadi, and J. G. Kuschewski, "An intelligent neuro-controller based on system parameter identification," *Proceedings of the IEEE Southeastcon '96*, Tampa, FL, April 11-14, 1996.

14. S. Zein-Sabatto, O. Omitowoju, and W. R. Hwang, "An intelligent neuro-system for failure detection and accommodation," *Proceedings of the IEEE Southeastcon '96*, Tampa, FL, April 11-14, 1996.

8.3 Non-refereed Papers

1. M. Essawy and M. Bodruzzaman, "Recurrent neural network-based monitoring and control of chaotic fluidized bed combustion (FBC) system," *Proceedings of 4th Annual HBCU/Private Sector/DOE R&D Technology Transfer Symposium*, Greensboro, NC, pp. 11-14, April 2, 1996.

2. M. Essawy and M. Bodruzzaman, "Using a recurrent neural network for chaotic behavior control," Accepted to World Congress on Neural Networks (WCNN '96) Conference, San Diego, CA, September 15-20, 1996.

3. J. G. Kuschewski and S. Zein-Sabatto, "Discrete dynamic system parameter identification and state estimation using a recurrent neural network," *Proceedings of World Congress on Neural Networks (WCNN '95) Conference*, Washington D.C., July 17-21, 1995.

4. W. R. Hwang, J. G. Kuschewski, G. L. Yuen, and S. Zein-Sabatto, "Reinforcement learning controllers for dynamic systems," *Proceedings of World Congress on Neural Networks (WCNN '95) Conference*, Washington D.C., July 17-21, 1995.

5. G. L. Yuen and C. Keaton, "Dynamic current-voltage characteristics in neuronal dendrites," *Proceedings of World Congress on Neural Networks (WCNN '95) Conference*, Washington D.C., July 17-21, 1995.

6. G. L. Yuen and C. Keaton, "Oscillatory hippocampal network models for spatial information processing," Accepted to Cell Signaling and Neuronal Plasticity Symposium at Meharry Medical College, Nashville, TN, July 18-19, 1996.

7. S. L. Morgan, G. L. Yuen, T. J. Teyler, and J. S. Spruill, "Effects of long-term depression in a model of hippocampal navigation," *To Appear in the Proceedings of the Annual Meeting of the Society for Neuroscience*, 1996.

8. A. S. Maida, G. L. Yuen, and C. G. Prince, "Visualization of neurodynamics in a model for spatial navigation," Accepted to World Congress on Neural Networks (WCNN '96) Conference, San Diego, CA, September 15-20, 1996.

9. G. L. Yuen, A. S. Maida, and C. G. Prince, "Neurodynamics of a spatial navigation model with long-term depression," Accepted to World Congress on Neural Networks (WCNN '96) Conference, San Diego, CA, September 15-20, 1996.

10. S. Zein-Sabatto, W. R. Hwang, and J. G. Kuschewski, "Neuro-observer for aircraft state reconstruction," *Proceedings of World Congress on Neural Networks (WCNN '95) Conference*, Washington D.C., July 17-21, 1995.

11. S. Zein-Sabatto, O. Omitowoju, and W. R. Hwang, "An intelligent non-parametric system identifier for failure detection in aircraft," Accepted to World Congress on Neural Networks (WCNN '96) Conference, San Diego, CA, September 15-20, 1996.

9 Faculty Presentations

1. Dr. Bodruzzaman presented "Neural network-based control of fluid bed combustion system" to the technical group of Morgantown Energy Technology Center, Morgantown, WV, March 12, 1996.

2. Dr. Bodruzzaman presented "Recurrent neural network-based monitoring and control of chaotic fluidized bed combustion (FBC) system," 4th Annual HBCU/Private Sector/DOE R&D Technology Transfer Symposium, Greensboro, NC, April 2, 1996.

3. Dr. Bodruzzaman will present "Using a recurrent neural network for chaotic behavior control," World Congress on Neural Networks (WCNN) Conference, Sept. 15-20, 1996.

4. Dr. Bodruzzaman will present "Iterative prediction of chaotic time-series using recurrent neural network," ANNIE '96, St. Louis, MO, November 1996.

5. Dr. Kuschewski presented "Discrete dynamic system parameter identification and state estimation using a recurrent neural network," World Congress on Neural Networks (WCNN), Washington, D.C., July 17-21, 1995.

6. Dr. Kuschewski gave tutorial lecture on "Genetic algorithms: fundamental concepts and application areas" to CNE staff on February 22, 1996.

7. Dr. Kuschewski gave final briefing on "AS&T Summer Project: Launch Vehicle Acoustic Suppression Technology (1 of 2)" to McDonnell Douglas Aerospace (MDA) staff on July 26, 1996.

8. T. Robinson presented "Adaptive filtering using Youla parameterization and neural network," World Congress on Neural Networks (WCNN), Washington D.C., July 17-21, 1995.

9. Dr. Yuen presented "Dynamic current-voltage characteristics in neuronal dendrites," World Congress on Neural Networks (WCNN), Washington, D.C., July 17-21, 1995.

10. Dr. Yuen presented "Theories of spatial navigation," University of Southwestern Louisiana, April 1996.

11. Dr. Yuen will present at the Symposium on Neural Networks, organized by the Metacenter Region Alliance/Joint Institute for Computational Sciences, University of Tennessee at Knoxville, August 23, 1996.

12. Dr. Yuen will present "Oscillatory hippocampal network models for spatial information processing," at the Cell Signaling and Neuronal Plasticity Symposium at Meharry Medical College, Nashville, TN, July 18-19, 1996.

13. Dr. Yuen will present "Visualization of neurodynamics in a model for spatial navigation," World Congress on Neural Networks (WCNN) Conference, Sept. 15-20, 1996.

14. Dr. Yuen will present "Neurodynamics of a spatial navigation model with long-term depression," World Congress on Neural Networks (WCNN) Conference, Sept. 15-20, 1996.

15. Dr. Yuen will present "Effects of long-term depression in a model of hippocampal navigation," poster presentation at the Annual Meeting of the Society for Neuroscience, 1996.

16. Dr. Zein-Sabatto presented "Neuro-observer for aircraft state recognition," World Congress on Neural Networks (1995), Washington D.C., July 17-21, 1995.

17. Dr. Zein-Sabatto presented "An intelligent neuro-controller based on system parameter estimation," IEEE Southeastcon '96, Tampa, FL, April 11-14, 1996.

18. Dr. Zein-Sabatto presented "An intelligent neuro-system for failure detection and accommodation," IEEE Southeastcon '96, Tampa, FL, April 11-14, 1996.

19. Dr. Zein-Sabatto will present "An intelligent non-parametric system identifier for failure detection in aircraft," World Congress on Neural Networks (WCNN) Conference, Sept. 15-20, 1996.

10 Participation in Proposals

The Center faculty participated actively in submitting proposals to various agencies as follows:

1. "Localization of Ventricular Arrhythmogenic Foci." Principal Investigator: Dr. M. Bodruzzaman. Agency: U.S. Department of Veteran Affairs (VA), Washington, D.C. Total Amount: **$170,406** for 3 years. Period: April 1, 1996 - March 31, 1999.

2. "Video Image Compression." Principal Investigator: Dr. M. Bodruzzaman. Subcontract from the Center of Excellence in COMmunication (CECOM) at NC State University. Agency: Department of Defence (DoD). Contract No. DAAB07-93-C-B768. Total Amount: **$35,000** for 1 year. Period: September 1, 1995 - August 31, 1996.

3. "Neural Network-based Monitoring and Control of Fluidized Bed." Principal Investigator: Dr. M. Bodruzzaman. Agency: US Department of Energy (DOE), Morgantown Energy Technology Center (METC). Grant No. DE-FG22-94MT94015. Total Amount: **$99,948** for 18 months. Period: January 1, 1995 - December 31, 1996.

4. "Advancing the Development of FMO Technology in Reliability Centered Maintenance." Co-Principal Investigators: Dr. M. Bodruzzaman, Dr. A. Shirkhodaie. Agency: Lockheed Martin Marietta Energy Systems (MMES). Total Amount: **$40,000.** Period: May 1996 - April 1997.

5. "Nonlinear Active Control of Dynamical Systems." Principal Investigator: Dr. M. Bodruzzaman. A white paper submitted to URI/DOD in Corsortium with UTK and Purdue University for a total estimated budget of **$1.2 Million**, December 1995.

6. "Neural Network and Wavelet Transform-based Image Processing Lab." Principal Investigator: Dr. M. Bodruzzaman. Submitted to Raytheon Company. Total Amount: **$80,000** for 1 year. December 1995.

7. "Intelligent Fault Dignosis System for Predictive and Preventive Maintenance of Pumps and Motors." Co-Principal Investigator: Dr. M. Bodruzzaman. Submitted to DOE. Total Amount: **$80,000** for 1 year. November 1995.

8. "Research Improvement in Minority Institutions (RIMI)." Co-Principal Investigators: Dr. M. Bodruzzaman, Dr. A. Shirkhodaie. Submitted to NSF. Total Amount: **$149,958** for 2 years. May 1996.

9. "Vibration and Motor Current Signature Analysis." Principal Investigator: Dr. M. Malkani. Co-principal Investigators: Dr. M. Bodruzzaman, Dr. A. Shirkhodaie. Agency: Facility Management Organization (FMO): Y-12 Plant, Martin Marietta Energy Systems (MMES), Oak Ridge, TN. Total Amount: **$80,000** for 1 year. Period: May 1995 - April 1996.

10. "Frequency-Dependent Learning Hippocampal Navigation Network." Principal Investigator: G. Yuen. Agency: National Science Foundation. Status: Currently under review.

11. "Learning of Non-unique Mappings and Application to Control" Principal Investigator: Dr. S. Zein-Sabatto. Agency: NASA (Lewis).

12. "White Paper (Concept Proposal) on Intelligent Design of Electric Induction Motors." Co-Principal Investigators: S. Zein-Sabatto, J. G. Kuschewski, and W. R. Hwang. Agency: MagneTek, Inc.

11 Faculty Self Improvement Activities

11.1 Activities of Dr. Bodruzzaman

1. Attended 1995 World Congress on Neural Networks (WCNN '95) Conference, Washington DC., July 17-21, 1995.

2. Attended 4th Annual HBCU/Private Sector/DOE R&D Technology Transfer Symposium, Greensboro, NC, April 2, 1996.

3. To attend 1996 World Congress on Neural Networks (WCNN '96) Conference, San Diego, CA, September 15-20, 1996.

11.2 Activities of Dr. Kuschewski

1. Attended monthly research series meetings between Vanderbilt University's Center for Intelligent Systems and TSU's Center for Neural Engineering.
2. Attended 1995 World Congress on Neural Networks (WCNN '95) Conference, Washington, D.C., July 17-21, 1995.
3. Attended Parallel Computing Workshop for HBCUs organized by JICS, UT Knoxville, May 20-31, 1996.
4. Participated in 5 Week AS&T Summer Project: Launch Vehicle Acoustic Suppression Technology (1 of 2) at McDonnell Douglas Aerospace, Space and Defense Systems, Huntington Beach, CA (MDA-S&DS-HB).
5. Principal architect and builder of the World Wide Web (WWW) Site for the CNE at TSU.

11.3 Activities of Dr. Yuen

1. Attended monthly research series meetings between Vanderbilt University's Center for Intelligent Systems and TSU's Center for Neural Engineering.
2. Attended 1995 World Congress on Neural Network (WCNN '95) Conference, Washington D.C., July 17-21, 1995.
3. Attended Parallel Computing Workshop for HBCUs organized by JICS, UT Knoxville, May 20-31, 1996.
4. To attend Cell Signaling and Neuronal Plasticity Symposium at Meharry Medical College, July 18-19, 1996.
5. To attend 1996 World Congress on Neural Networks (WCNN '96) Conference, San Diego, CA, September 15-20, 1996.

11.4 Activities of Dr. Zein-Sabatto

1. Attended 1995 World Congress on Neural Networks (WCNN '95) Conference, Washington DC., July 17-21, 1995.
2. Organized and attended monthly lecture series for researchers from TSU and Vanderbilt University.
3. Attended IEEE Southeastcon '96 Conference, Tampa, FL, April 11-14, 1996.
4. Chaired a Session in Neural Networks at IEEE Southeastcon '96 Conference, Tampa, FL, April 11-14, 1996.

5. To attend 1996 World Congress on Neural Networks (WCNN '96) Conference, San Diego, CA, September 15-20, 1996.

12 Distinguished Lecture Series

12.1 Monthly Lecture Series

As a spin-off of CNE, researchers at Tennessee State University's Center for Neural Engineering and researchers at neighboring Vanderbilt University's Center for Intelligent Systems met during Spring 1995 semester and agreed to share their resources and submit joint proposals for funding. To simulate the exchange of ideas it was agreed to immediately start a monthly lecture series. The researchers both at TSU/CNE and VU/CIS toured each other's facilities and greater synergies are expected to be generated during 1996-97 school year.

13 Recruitment of Research Associates

The CNE hired Dr. Magdi Essawy, a very competent Post-Doctoral Research Associate. Magdi received a B.S. in Electrical Engineering from El-menoufia University, Egypt, in 1984, with distinction with highest honors, a M.S. in Electrical Engineering from the University of Cairo, Egypt, in 1990, and a Ph.D. in Nuclear Engineering, from the University of Tennessee, Knoxville, in August 1995. His interests include, neural networks, nuclear power plant safety, power plant monitoring, system modeling, system control, chaotic behavior analysis and control, wavelet theory, expert systems, fuzzy logic, genetic algorithms, medical diagnosis, and signal processing. He is a valuable asset to the CNE.

14 Programs for Students

14.1 Student Recruitment Activities

We continue to recruit the students to conduct research in the Center for Neural Engineering as follows:

1. An Announcement is posted on the College Bulletin Board for graduating seniors with a GPA of at least 3.0 out of possible 4.0 to apply with a copy of transcript and a letter expressing their interest to conduct research at the Center. A student must agree to complete their senior project at the Center and that a student must set aside a block of at least three hours to conduct research.

2. Outstanding juniors are also involved in research and looked upon as potential candidates to generate a pipeline.

3. Undergraduate students are exposed to the field of neural networks through the distinguished lecture series program.

4. Demonstrations are being set up in the Center to motivate the students in this technology.

5. Recruitment poster and related literature is sent our sister HBCU/MI institutions to recruit graduate students.

6. Announcements are placed at the national NSBE and SWE conventions.

7. The college also participates in Science and Engineering graduate recruitment fairs.

8. Announcements are sent periodically to other universities with engineering programs.

14.2 Summer Educational/Enrichment Programs

1. Carolyn Keaton, Tim Robinson and Jarvis Spruill attended the WCNN '95 conference at Washington DC, July 17-21, 1995. Tim Robinson presented a paper on "Adaptive filtering using Youla parameterization and neural networks" at the conference. Carolyn Keaton co-authored a paper with Dr. Yuen that was presented at the conference.

2. Tim Robinson spent summer 1995 at the CNE completing his Masters Thesis.

3. Carolyn Keaton, Vivian Doresy, and Jarvis Spruill spent summer 1995 at the CNE. They interacted with MMC to collect data for their research.

4. Vivian Dorsey will spend summer 1996 at General Motors in Michigan to gain industrial experience.

5. Steven Drews will spend summer 1996 at the ORNL robotics laboratory under Dr. Francoise Pin to gain hardware experience in applying fuzzy logic to robotics.

6. Deimetra Moore will spent summer 1996 at Caltech to interact with researchers in helicopter control systems.

7. Kevin McFerrin and Christopher Mosby will spend summer 1996 at ORNL in the predictive maintenance and diagnostic area.

14.3 Research Opportunities and Internships

All graduate research assistants are provided the opportunity to work half time (maximum 20 hours per week) during the school year and full time (40 hours per week) during summer. Undergraduate assistants can work a maximum of 10 hours per week during academic year and full time during summer. During the academic year research can be done at TSU, MMC, ORNL, or Caltech.

Due to our unique teaming arrangement, the students are provided the opportunity to spend either full or part summer at our consortium partners, thus proving a variety of experience to the student to enhance his/her professional development. This could lead to a challenging Master's thesis and a journal article.

Students attending at Meharry Medical College are exposed to basic electrophysiological techniques associated with the recording of bio-electric events from live animals to include protocol development, animal surgery, instrumentation, analysis as well as ethical and humane considerations. This program could be enhanced by pairing students on a long term basis with Ph.D. level neuroscience students working in this laboratory.

14.4 Mentoring Programs

Each research assistant is provided a TSU faculty member as a mentor. The mentor meets with the student at least once a week or more as the need may be. During summer months a student could have two mentors if he/she is spending summer at consortium partners facility. However a TSU faculty member will be the primary thesis advisor and this is made clear to consortium partners.

15 Facilities and Equipment

The Center of Neural Engineering in collaboration with a grant from NASA on Robust Integrated Neurocontroller now has eight (8) 486-based IBM compatible PCs, six (6) Pentium based PCs and two (2) HP laser printers. CNE has also purchased EKG, EMG and EEG recording equipments to enhance the research capabilities of the Center. A small model of helicopter is also acquired by the Center, since many students have shown interest in helicopter control system using neural networks. A mobile robot is being purchased to serve as a testbed for spatial navigation neural networks being developed at the CNE. When fully implemented CNE will be able to show on-line demonstration at all times. A blower and a dual motor set is donated by ORNL to enhance research activities in predictive maintenance and diagnosis analysis.

16 Specific Program Objectives for Next Year

It is envisioned that with a greater interaction among consortium partners a well focused research will be conducted leading to quality research and journal papers. The specific objectives of various researchers are listed below.

16.1 Goals of Dr. Bodruzzaman

Dr. Bodruzzaman will interact with ORNL scientists, Dr. Bhattacharyyia at Meharry Medical College, and Dr. Yaser Abu-Mostafa at Caltech. His specific goals for the next year are as follows:

1. Generate 2 refereed papers and 2 conference papers with consortium partners at Meharry Medical College.

2. Mentor 3 undergraduate students in supervising their senior projects in the area of neural networks.
3. Mentor 3 graduate students in supervising their Masters projects in the area of neural networks.
4. Develop and conduct necessary experiments to acquire epicardial data in collaboration with Dr. Bhattacharyyia of MMC.
5. Develop collaboration with Dr. Bhattacharyyia at MMC in developing undergraduate and graduate projects in the area of medical dignosis of cardiac system using chaos analysis methods and neural network techniques.
6. Interact with Dr. Yaser Abu-Mostafa of Caltech on medical diagnosis research.
7. Develop senior and Masters projects in the area of neural network-based predictive maintenance in collaboration of ORNL scientists.
8. Teach graduate level neural network course (EE503) in fall 1996.
9. Develop graduate course in image processing.
10. Initiate bio-medical engineering option at the graduate level.

16.2 Goals of Dr. Kuschewski

His specific goals for the next year are as follows:

1. Generate 3 peer reviewed conference and journal papers with consortium partners.
2. Develop funded research program in the area of genetic algorithms.
3. Develop and implement software and hardware platform for mobile robot.
4. Co-advise 3 graduate students.

16.3 Goals of Dr. Yuen

Dr. Yuen will continue to interact with Dr. Tim Teyler at NEOUCOM (biological learning rule investigation), Dr. Anthony Maida at University of Southwestern Louisiana (navigational neural network architecture software development), and Dr. K. L. Wong at University of Tennessee at Knoxville/Oak Ridge National Laboratory (parallel computing). His specific goals for the next year are as follows:

1. Generate 3 refereed papers and 3 conference papers with consortium partners.
2. Mentor 2 graduate students in their Masters projects in the area of biological neural networks.

3. Develop and implement hardware platform for mobile robot using biological navigational neural network.

4. Continue collaboration with Dr. Wong to develop parallel computer version of biological simulator for navigation.

5. Understand how oscillations in hippocampus can interact with frequency-dependent learning and spatial navigation (e.g. place fields, population code for spatial location, hippocampal rhythms).

16.4 Goals of Dr. Zein-Sabatto

Dr. Zein-Sabatto will interact with researchers from Caltech and Vanderbilt University. His specific goals for the next year are as follows:

1. Complete the helicopter testbed project and start implementing neural network and fuzzy logic for modeling and closed-loop control of the helicopter.

2. Continue the development of neurocontrol systems based on actual biological sensory motor control with application to spherical servomechanism.

3. Continue the development of the time delay between pre-synaptic and post-synaptic responses and provide results to MMC.

4. Mentor 3 undergraduate and develop senior projects for them in the neural network and control systems area.

5. Mentor 4 graduate students and develop Masters Theses for them in the area of biological NN, modeling and control systems.

6. Publish journal articles jointly with Vanderbilt University.

7. Implement the development of naviagation learning in the Hippocampus by Jarvis Spruill on a real-world engineering problem.

8. Apply for patent on joint controller.

17 Consortium Interaction

17.1 Interaction between TSU and Caltech

Three researchers from Caltech, Dr. Yaser Abu-Mostafa (Professor, Electrical Engineering), Dr. Giacomo Indiveri (Research Fellow), and Eric Box (Ph.D. Student) visited TSU in March 1996 to enhance collaboration efforts. Drs. Abu-Mostafa and Indiveri presented seminars to both faculty and graduate students of TSU and MMC, while Eric Box interacted with

graduate and undergraduate students. It was a very fruitful meeting; the first development may be a joint research collaboration in medical diagnosis.

As a follow up, Tamara Williams (Sophomore in Physics, TSU) and Deimetra Moore, (Graduate Student, Electrical and Computer Engineering) will spend summer 1996 at Caltech interacting with researchers and developing professionally. Such visits will lay the foundation for better collaboration between the faculty at TSU and Caltech.

17.2 Interaction between TSU and MMC

The research on cardiac systems is being conducted in collaboration with Dr. Mohit Bhattacharyyia, Professor of Physiology, MMC. We are using the experimental setup and data acquisition system of MMC. Dr. Bhattacharyyia and his colleagues at MMC are helping us design the experiment, dissect the dog's heart, and develop the direction of the data analysis that is needed. One graduate student and one faculty member from TSU, Dr. Bodruzzaman, are collaborating with Dr. Bhattacharyyia at MMC. We are hopeful that this collaboration will result in receipt of a major grant from NIH.

17.3 Interaction between TSU and NEOUCOM

The CNE awarded a subcontract to NEOUCOM to support Steve Morgan, a Ph.D. student under the guidance of Dr. Tim Teyler, Professor of Physiology at NEOUCOM. Dr. Teyler has been interacting with Dr. Yuen and the research effort involves behavioral tests of some of the predictions of the spatial navigation model. Essentially, the frequency dependent learning rule specifies that the two forms of synaptic plasticity are frequency dependent and may serve different functions. The details of his report are presented under Dr. Teyler's research activities.

17.4 Interaction between TSU and ORNL

This year the interaction with ORNL took a very positive and much more interactive role, mostly due to Dr. Ed Oliver who succeeded Dr. Bill Appleton on the CNE Board of Directors. Dr. Oliver is the Director of Education, Computer and Robotics Division at ORNL and the CNE is fortunate to have him as a Director.

At the invitation of Dr. Oliver, about 8 of our faculty members visited the Computational Center for Industrial Innovation (CCII) and the Robotics Laboratories at ORNL on April 17, 1996 to tour the facilities and interact with their scientists and engineers. As a result, Drs. Kuschewski, Yuen, and Tao attended two to five days of a workshop on parallel computing at UTK under the Joint Institute for Computational Science (JICS). At our request, Dr. Oliver also sent three computer networking experts to assess our computing facilities and bring them to state of the art, including video conferencing capability.

As a spin off of the above interaction, four undergraduates and three graduate students will spend summer 1996 at ORNL and Y-12 plant conducting research in machine vibration diagnosis, predictive maintenance, and robotics.

It is projected that the interaction with ORNL will lead to joint research projects and much more active involvement in the activities of the CNE, especially by Dr. Harvey Gray, Director of CCII, Dr. Francoise Pin, Head of the Robotics Laboratory, and Stan Bunch, Manager of the Predictive Maintenance Facility at the Y-12 plant.

17.5 Interaction between TSU and USL

Dr. Tony Maida, Professor of Computer Science at USL has been interacting very effectively with Dr. Yuen. Dr. Maida has implemented the Burgess Model in C, reducing the time required to simulate the model to 35 minutes, compared to 9 days for a similar model implemented in Matlab. Through Dr. Yuen, Dr. Maida is interacting with JICS staff to access their high performance computing facilities to reduce model simulation time even further. Dr. Maida and Dr. Yuen have also contributed two papers to WCNN '96 for presentation and publication.

17.6 Summary

Thus with the interaction between Caltech, MMC, NEOUCOM, ORNL, USL, and TSU, the research in neural computation by all consortium members will be greatly enhanced during 1996-97. Hopefully, one research result will be new neural network architectures for application to spatial navigation.

PART II

18 Information on Seniors and Graduate Students in The Program

During the school year 1995-96 a total of five (5) seniors and fourteen (14) graduate students participated in the Center of Neural Engineering (CNE). They conducted research on various topics under the supervision of faculty mentors. Four (4) senior projects and three (3) Master Theses were funded by NASA and the rest by ONR. Under this grant, one senior completed his research project which transformed into a senior project and two graduate students completed Master Theses during the academic year 1995-1996.

The names of the students, their major field of study, their faculty mentor, the name of their graduate school or their employer upon graduation, and their project title is listed below:

18.1 Undergraduate Students

1. Larry Word
   - Major Field of Study: Electrical and Computer Engineering
   - Faculty Mentor: Dr. Zein-Sabatto
   - Date of Graduation: May, 1996
   - Graduate School:
   - Employer:
   - Project Title: Design of a Neural Controller for the Control of the Inverted Pendulum

18.2 Graduate Students

1. Vivian Dorsey
   - Major Field of Study: Electrical and Computer Engineering
   - Faculty Mentors: Dr. Zein-Sabatto (TSU), Dr. Kuschewski (CNE)
   - Date of Graduation: December, 1996 (expected)
   - Graduate School: Tennessee State University
   - Employer:
   - Research Title: Design of Artificial Limb Using Spherical Joints
2. Anuradha Gulamudi

- Major Field of Study: Electrical and Computer Engineering
- Faculty Mentor: Dr. Bodruzzaman (TSU), Dr. Yuen (CNE)
- Date of Graduation: December, 1996 (expected)
- Graduate School: Tennessee State University
- Employer:
- Thesis Title: Oscillatory Neural Network for Invariant Target Recognition

3. Carolyn Keaton
    - Major Field of Study: Electrical and Computer Engineering
    - Faculty Mentors: Dr. Yuen (CNE), Dr. Bodruzzaman (TSU), and Dr. Teyler (NEOUCOM)
    - Date of Graduation: August, 1996 (expected)
    - Graduate School: Tennessee State University
    - Employer: Lucent Technologies
    - Thesis Title: Oscillatory Neural Networks for Spatial Information Processing
4. Srinivasa Ramamurthy
    - Major Field of Study: Electrical and Computer Engineering
    - Faculty Mentor: Dr. Bodruzzaman
    - Date of Graduation: May, 1996
    - Graduate School:
    - Employer: Lucent Technologies
    - Thesis Title: Neural Network-based Target (Image) Recognition and Classification
5. Jarvis Spruill
    - Major Field of Study: Electrical and Computer Engineering
    - Faculty Mentors: Dr. Yuen (TSU), Dr. Zein-Sabatto (TSU)
    - Date of Graduation: May, 1996
    - Graduate School:
    - Employer: International Paper Company
    - Thesis Title: Long Term Potentiation Learning Rules with Application to Neural Engineering

19 Tracking of Graduates Under this Grant

A list of graduated students and their current status are given below:

1. Ronnie Harper
   - Major Field of Study: Electrical Engineering
   - Date of Graduation: December, 1992
   - Employer: General Motors Corporation
2. Lamar Crowder
   - Major Field of Study: Electrical Engineering
   - Date of Graduation: May, 1993
   - Employer: Delco Electronics (GM)
3. Wayne Garrison
   - Major Field of Study: Electrical Engineering
   - Date of Graduation: May, 1993
   - Employer: International Paper
4. Anthony Wilson
   - Major Field of Study: Electrical Engineering
   - Date of Graduation: May, 1993
   - Graduate School: Georgia Tech
5. Mario Yancy
   - Major Field of Study: Electrical Engineering
   - Date of Graduation: May, 1994
   - Graduate School:
6. Lisa Callway
   - Major Field of Study: Electrical Engineering
   - Date of Graduation: May, 1994
   - Graduate School: Prairie View A&M University
7. Vivian Dorsey
   - Major Field of Study: Electrical Engineering
   - Date of Graduation: May, 1994

- Graduate School: Tennessee State University

8. Edna Jones
    - Major Field of Study: Electrical Engineering
    - Date of Graduation: August, 1994
    - Graduate School: Tennessee State University
9. Richard Griffin
    - Major Field of Study: Electrical Engineering (M.E. Degree)
    - Date of Graduation: December, 1994
    - Employer: Tennessee State University
10. Bridgitte Bundrage
    - Major Field of Study: Electrical Engineering (M.E. Degree)
    - Date of Graduation: May, 1995
    - Employer: Raytheon Corporation
11. Larry Word
    - Major Field of Study: Electrical Engineering
    - Date of Graduation: May, 1996
    - Employer:
12. Jarvis Spruill
    - Major Field of Study: Electrical Engineering (M.E. Degree)
    - Date of Graduation: May, 1996
    - Employer: International Paper Company
13. Srinivasa Ramamurthy
    - Major Field of Study: Electrical Engineering (M.E. Degree)
    - Date of Graduation: May, 1996
    - Employer: Lucent Technologies

20 Enrollment and Academic Performance Data

Table 2: Enrollment data.

	Number of students enrolled at school (by year) Fall 1995				Number of students enrolled in ONR program (by year)				Number of students graduated Aug.'95 & May'96		Number to Graduate or Professional School	
Major Discipline (Science Engineering)	1 Fr.	2 Sph	3 Jr.	4 Sr.	1 Fr.	2 Sph	3 Jr.	4 Sr.	Total	ONR	Total	ONR
Biology	172	75	87	116				1	50		10	
Chemistry	30	14	14	16					14		6	
Computer Science	89	50	55	37					26		8	
Engineering	296	120	130	209			4	1	47	1 (2)	10	3
Mathematics	17	8	7	17					7		2	
Physics	3	1	1	3					3		1	
Totals for Science and Engineering	607	158	294	388			4	2	147	1 (2)	37	3

( ) Graduate Students

Table 3: Academic performance data.

Class Year	Mean SAT (ACT) for all Freshmen	Mean SAT (ACT) for ONR Freshmen	Mean GPA for all Students	Mean GPA for ONR Students	Mean GRE for all Students	Mean GRE for ONR Students
1 1992	19	N/A	2.74	N/A	N/A	N/A
2 1993	19.3	N/A	2.92	3.2		
3 1994	19.8	N/A	2.95	3.2		
4 1995	20.1	N/A	2.95	3.2		